

PLASMA SYSTEM OPERATION

PERKIN-ELMER

PREFACE

This manual will provide you with an instructional guide in the operation of a Perkin-Elmer sputtering system.

Although the following information is used for classroom instruction, the design allows you to continually refer back to this manual for future reference and/or a refresher in component capabilities.

This manual includes photos which will help you understand and provide a thorough presentation of the information. Each section and/or sub-assembly is accompanied by a fold-out photograph. This will enable you to fold out the appropriate photo for quick reference while you study.

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BASICS OF SPUTTERING

THE BASIC MECHANISM

Sputtering is a coating process which involves the transport of almost any material from a source, called a target, to a substrate of almost any other material.¹ The ejection of the source material is accomplished by the bombardment of the surface of the target with gas ions accelerated by a high voltage. Particles of atomic dimension from the target are ejected as a result of momentum transfer between incident ions and the target. The target-ejected particles traverse the vacuum chamber and are subsequently deposited on a substrate as a thin film.

Simply said, by electrically charging an induced gas (such as argon) within a vacuum chamber, it is possible to cause a collision of the atoms upon the electrically charged plate. This plate is known as the target or target material. The striking of these electrically charged atoms, or ions, at certain energy levels, physically remove atoms of the target material. These are then re-deposited on another surface. This second surface is the substrate location or material to be coated by the target material. Electrically, the target material is known as the cathode; the substrate receiving the material to be coated is the anode plate; and the electrically charged gases introduced produce the sputtering phenomenon called a self-sustaining glow discharge or "plasma." Basically, sputtering involves removing a material from one area or location and redepositing it on another surface, or another location. Sputtering is the physical ability to go from a solid state to a gaseous state and back to a solid state having never formed a liquid.

HISTORY

The first observations of metal deposition sputtered from a cathode discharge was reported in 1852 by Grove.² The original article is worth reading to fully appreciate the progress which has been made in the sputtering field since then. The history of sputtering can be traced most rapidly by reading a selection of survey articles showing the field in its proper perspective in time and corresponding date of physics knowledge. As early as 1877, sputter deposition was used to deposit thin films to coat mirrors. In the 1920's sputtering enjoyed a brief vogue in the coating of flimsy fabrics with gold.

In 1930, Western Electric Company sputter deposited gold which served as a base for subsequent electrolytic thickening. As vacuum technology became more sophisticated, sputtering was virtually replaced by vacuum evaporation which using electron beam or resistance heating techniques, offered higher rates of deposition. The interest of sputtering as a film deposition technique persisted because some materials could not be evaporated by the resistance heating method. Instead of depending on heat to vaporize the material, sputtering is an atom by atom process. In this manner, a high quality of film is gradually built up.

Sputtering literature has mushroomed in recent years. In 1956 Physics Abstract magazine listed five abstracts. This number swelled to more than one hundred by 1967. However, as the basic phenomenon became better understood, emphasis began to shift more and more from the target to the substrate, or from the base to the application side. Consequently, papers on sputtering are shifting in increasing numbers from the Physical Review to the Journal of Applied Physics, or such specialized journals as Thin Solid Films, Thin Films, and the Journal of Vacuum Science and Technology. This has happened within the last decade, spurring the industry to develop sputtering systems. This rapid growth within the last ten years has generated another need in the market place for raw materials for sputtering targets.

¹Maissel and Glang, "Handbook of Thin Film Technology," McGraw Hill Inc., 1970

²Grove, W. R. Phil:trans. Roy. Soc. London, 142, 87 (1852)

FACTS OF SPILLING

1970-1971

The following facts are based on the information received from the various sources mentioned in the preceding pages. It is not intended to be a complete list of all the facts, but rather a summary of the most important ones.

The first fact is that the spill occurred on the morning of January 1, 1970, at approximately 10:00 AM. The second fact is that the spill was caused by a failure of the valve on the main line.

The third fact is that the spill was contained within the main line and did not escape into the environment. The fourth fact is that the spill was discovered by the operator of the main line.

The fifth fact is that the spill was reported to the appropriate authorities. The sixth fact is that the spill was investigated by the appropriate authorities.

The seventh fact is that the spill was contained and the main line was repaired. The eighth fact is that the spill was not a recurrence of a previous spill.

The ninth fact is that the spill was caused by a failure of the valve on the main line. The tenth fact is that the spill was contained within the main line and did not escape into the environment.

The eleventh fact is that the spill was discovered by the operator of the main line. The twelfth fact is that the spill was reported to the appropriate authorities.

The thirteenth fact is that the spill was investigated by the appropriate authorities. The fourteenth fact is that the spill was contained and the main line was repaired.

The fifteenth fact is that the spill was not a recurrence of a previous spill. The sixteenth fact is that the spill was caused by a failure of the valve on the main line.

The seventeenth fact is that the spill was contained within the main line and did not escape into the environment. The eighteenth fact is that the spill was discovered by the operator of the main line.

The nineteenth fact is that the spill was reported to the appropriate authorities. The twentieth fact is that the spill was investigated by the appropriate authorities.

WHY SPUTTER?

Improved adhesion: The kinetic energy of sputtered atoms or molecules are orders of magnitude greater than that of other deposition processes.

Improved stoichiometry: The ease of depositing compounds and maintaining composition. (Often not possible for other methods).

Reproducibility: Ability to easily control and repeat accurately the deposition of thin films.

Flexibility: The nature of the process lends itself to adaptation for complex research applications as well as high volume production uses.

SPUTTERING APPARATUS

There are four major components required for sputtering: a vacuum system to evacuate the chamber, a target, a power supply, and the sputtering chamber.

Certain features are desirable in the operation of the system: simple operation with short set-up time; rapid change of both targets and substrates, separate control over as many of the sputtering variables as possible and reasonably high sputtering rates. Deposition rates, however, do not take precedence over adherence and the integrity of the film.

VACUUM

Several types of vacuum pumping may be used: D-P (diffusion pump), cryo, or turbomolecular. Most systems use a liquid nitrogen (cryotrap) between the high vacuum pump and the chamber. This provides a tremendous pumping speed for water vapor and other condensable gases. Only a small partial pressure of water, oxygen, or nitrogen can cause the deposition of non-stoichiometric films. This mechanism, called reactive sputtering (when performed deliberately) is explained later.

Once the sputtering chamber has been evacuated to the desired level, an inert gas, "the sputtering gas," is introduced in the system through a micrometer controlled leak valve. This gas may be argon, neon, etc. When a very clean sputtering procedure is desired, for example to produce a titanium film, it may be necessary to further cleanse the gas when it is fed into the chamber. This is accomplished with the use of a filter or titanium sublimation.

POWER SUPPLY

The power supply for sputtering may be DC (direct current) or RF (radio frequency). Selection depends on the type of sputtering to be performed (DC, RF, RF/bias, etc.) and the material to be deposited. In either case, the purpose of the power supply is the same: to generate the plasma and to induce sputtering by setting up a negative surface charge on the target.

TARGET

The target produces the material which is to be deposited as a thin film onto the substrate material. The shape and the construction of the target may vary depending on the material to be deposited and the size and shape of the substrate material. Generally, the target is disc shaped and consists of a backing or mounting plate and a layer of the target material.

PROCESSING CHAMBER

The basic sputtering chamber generally consists of, but is not limited to, the following components:

Chamber top plate: Provides the top seal of the vacuum chamber. Further, it serves as a platform on which the cathode assembly, water and electrical connections are made. In RF sputtering the tuning network is also mounted here.

Vacuum chamber: Usually made of stainless steel with a viewport for the sputtering process.

Cathode assembly: A coating material is mounted to a target backing plate which is in turn secured to the target holder (referred to as the *cathode*) and provides the deposition material.

A dark space shield: Surrounds the target and the cathode, prevents a plasma from being generated at the rear and the sides of the cathode, avoiding undesired sputtering from those areas.

Shutter: In a sputtering arrangement the shutter interrupts the flow of material from the target to the substrates, much like a camera shutter. The major difference is that it is possible to clean the target of microscopic surface impurities caused by handling, etc., by "pre-sputtering" onto the shutter.

Substrate holder: Usually a flat pallet that substrates sit on.

Anode: A table area that the pallet is located on during processing.

Micrometer leak valve: During the sputtering operation, when the chamber has been evacuated, a gas (usually argon) must be metered into the system. For this purpose a micrometer leak valve is incorporated into the sputtering chamber so that the flow of the "sputtering gas" may be precisely controlled.

PLANAR MAGNETRON

The planar magnetron offers sputtering rates on order of magnitude faster than conventional methods, along with reduced substrate heating. RF excitation is used for non-metals and DC for conductive materials.

THE PRIMARY USES OF SPUTTERING

Now that we have examined the process of sputtering and the equipment used, let us go back to the original definition.

Sputtering: A controlled method of coating almost anything with a thin film of almost any material.

With this basic description in mind, the applications for the sputter process are innumerable. The thinness of the coatings, the wide variety of materials to be deposited, and the ease of application provide the key to many of the possible uses for sputtering.

A GLOSSARY OF SPUTTERING TERMS

- Angstrom:** A measure based on the length of light waves. It equals one ten-thousandth of a micron or about one three-hundred-millionth of an inch. An average atom of material is two to three Angstroms in diameter.
- Anode:** The positive element or electrode which is generally the substrate holder in a sputtering system.
- Back Sputtering:** Also referred to as sputter or ion etching, back sputtering is the reversal of the sputtering process which is used to clean and prepare substrates prior to sputtering a film on them. To prevent contamination onto the target, back sputtering is generally done onto the shutter.
- Batch System:** A sputtering or other system which allows coating of a batch of substrates rather than continuous coating. At the end of the operation, the chamber is opened, the coated substrates removed and a new batch loaded for coating.
- Biasing:** Generally, the placing of a small negative potential on substrates, causing some degree of back sputtering during the regular sputter coating operation. It affects the composition and structure of the deposited coatings.
- Cathode:** A negatively charged electrode. In sputtering, the target or source of coating material is generally referred to as the cathode.
- Contamination:** The presence of undesirable foreign matter on the target, substrate or other components in a sputtering system.
- Dark Space:** Dependent on pressure, electrons from the target have relatively few chances to strike a gas molecule until they have traveled some distance. Thus a glow region does not develop close to the target.
- Dark Space Shield:** A ring which surrounds the target and cathode to prevent undesirable sputtering from the edges and rear of the target.
- Dielectric:** A non-conducting material (generally a ceramic or other compound) which is particularly difficult to coat using processes other than sputtering.
- In-Line Sputtering:** Multiple targets located in a single planar line. Substrates are sequentially passed under the targets.
- Ion Gauge:** A vacuum gauge which measures the high vacuum levels attained in the chamber prior to back filling with the ionizable gas for sputtering.
- Mechanical Roughing:** Fore pumping via a mechanical pump with rotating vanes and oil seals. Air from the chamber is caught and swept out to atmosphere by the vanes.
- Pallet:** A plate for holding the substrates placed on the anode when sputtering.
- Pre-sputtering:** A cleaning of surface impurities on the target prior to use for coating.
- Reactive Sputtering:** A process which takes place with a gas in the sputtering chamber which reacts either with atoms or molecules of target material as they move through the chamber, or with the coating material on the substrates.
- RF Bias Sputtering:** A system of simultaneous etching and sputtering which lowers impurity concentration in coated films and offers additional control of film density, adhesion and structure.
- Roughing Pump:** A pump which brings the desired chamber from atmosphere to the micron range.
- Shutter:** A platen or other device used to interrupt the flow of material from the targets to the substrates.
- Spectroscopy:** Mass spectographic analysis is a method for detecting impurities in the parts-per-million range when evaluating solid elements. It is used for quality control in the production of MARZ grade metals and ceramics for sputtering targets and other uses.
- Sputtering:** A coating process which involves the transport of almost any material from a source, called a target, to a substrate of almost any other material. The ejection of the source material is accomplished by the bombardment of the surface of the target with gas ions accelerated by a high voltage. Particles of atomic dimensions from the target

are ejected as a result of momentum transfer between incident ions and the target. The target ejected particles traverse the vacuum chamber and are subsequently deposited on a substrate as a thin film.

Stoichiometry: Measure of the ratio of atoms of various materials in an alloy or compound. A stoichiometric film is one which has the proper ratio.

Torr: A term of vacuum measurement equivalent to one millimeter of mercury. Sputtering operations normally take place in a vacuum pressure range of 1×10^{-3} to 100×10^{-3} torr (also referred to as one to one hundred microns).

Tuning Network: A tuning network matches the power from the power source to the needs of the particular sputtering operation. (A tuning network is not required for a simple DC sputtering.)

Vacuum: Absence of gas, i.e., having fewer gas molecules present than exist at atmospheric pressure. Degrees of vacuum are indicated as "partial vacuum," "rough vacuum," "medium vacuum," "high vacuum," and "ultra-high vacuum." Sputtering takes place in a rough or medium vacuum, after the process chamber has first been clean-pumped to high vacuum and a gas leaked back in.

Vacuum Chamber: Generally, a stainless steel enclosure in which sputtering takes place.

Vacuum Pumping Station: A system consisting of several vacuum pumps which is used to evacuate the vacuum chamber.

Pressure Conversion Table

Atmosphere	=	760 Torr	=	760 millimeters Hg
1000 millitorr	=	1 Torr	=	1.332×10^2 PASCAL (Pa)
100 millitorr	=	.1 Torr	=	1×10^{-1} Torr ≈ 13.33 Pa
1 millitorr	=	1 Micron	=	1×10^{-3} Torr $\approx 1.33 \times 10^{-1}$ Pa
Gauge X-ray limit	=		=	2×10^{-11} Torr $\approx 2.66 \times 10^{-9}$ Pa

Note: "millitorr" and "micron" are interchangeable terms.

1 Torr

1 MILL MICRON $\approx 10^{-6}$ mm Hg

1 MILL BAR $\approx .75$ mm Mercury

1 BAR ≈ 75 mm Hg ≈ 29.53 in Hg

1 MICRO Hg $= 10^{-3}$ mm Hg $= .001$ mm Hg

outer space 1×10^{-11} Torr

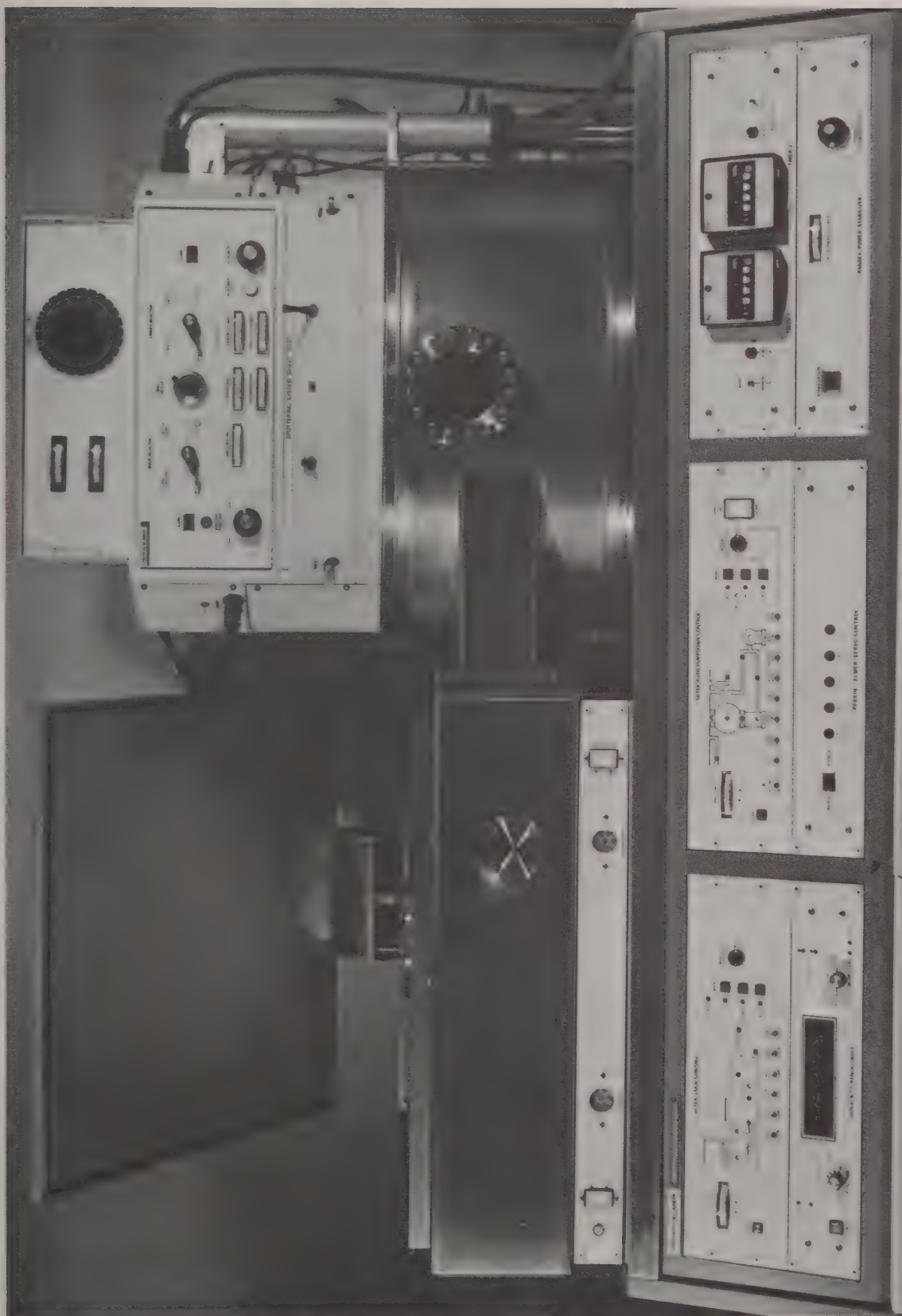
1 MICRON $= 10,000 \text{ \AA}$

BASIC SUBASSEMBLIES

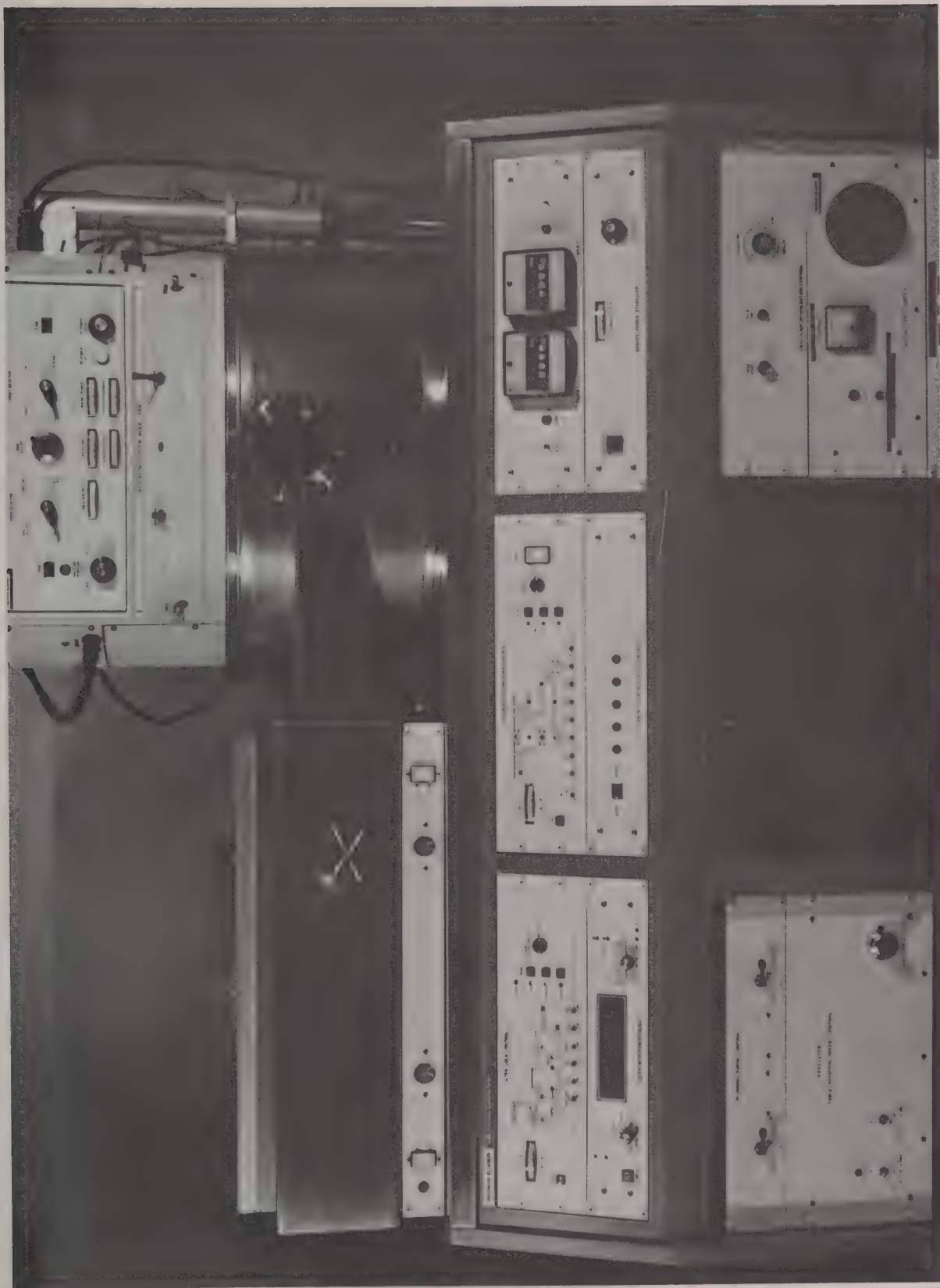
The best way to understand what the sputtering system is capable of doing and how to maintain it, is to first learn how to operate its subassemblies.

First, a labeled system overview is provided for your reference. A brief explanation about each subassembly follows.





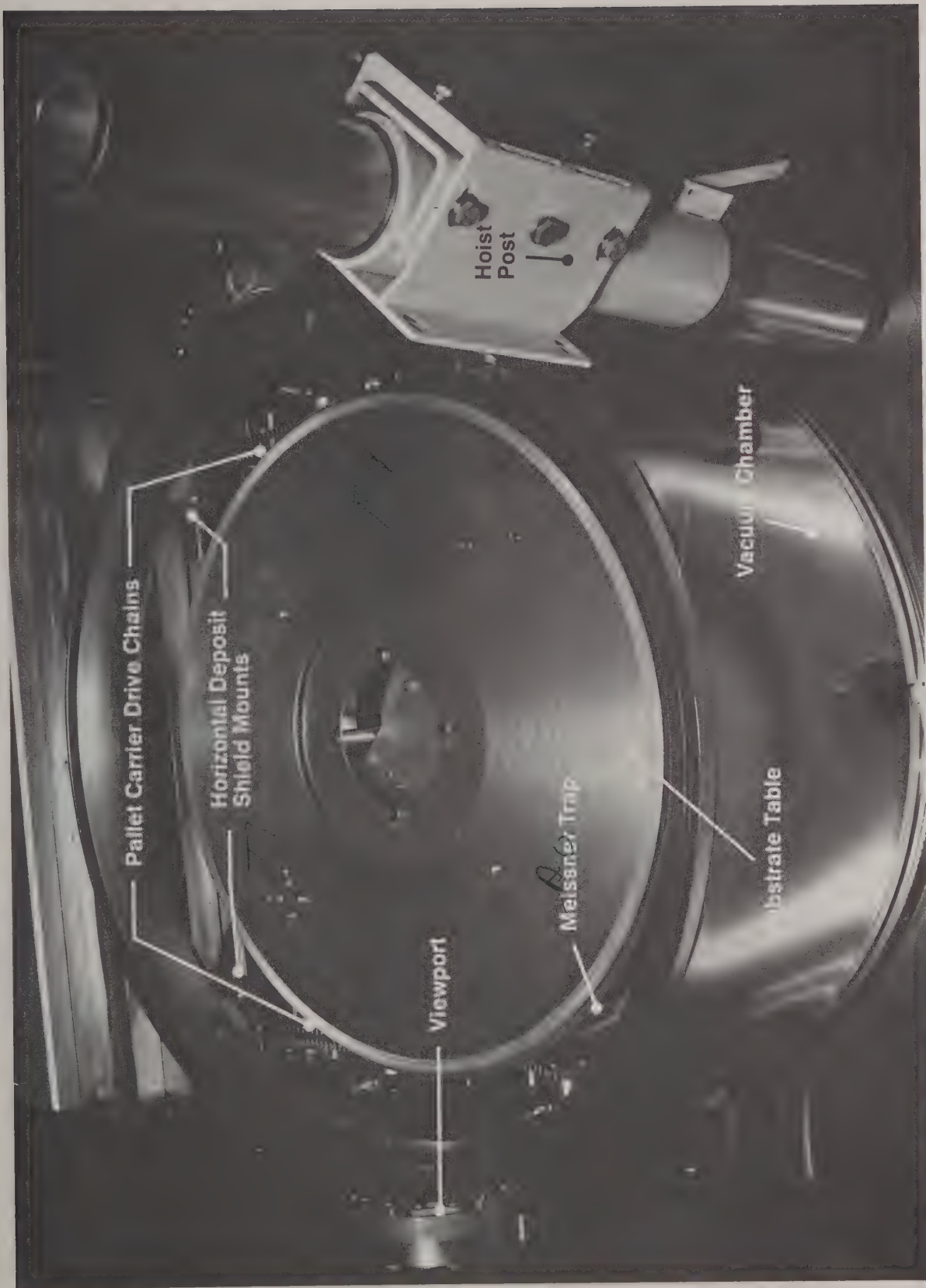
4400 Series Sputtering System



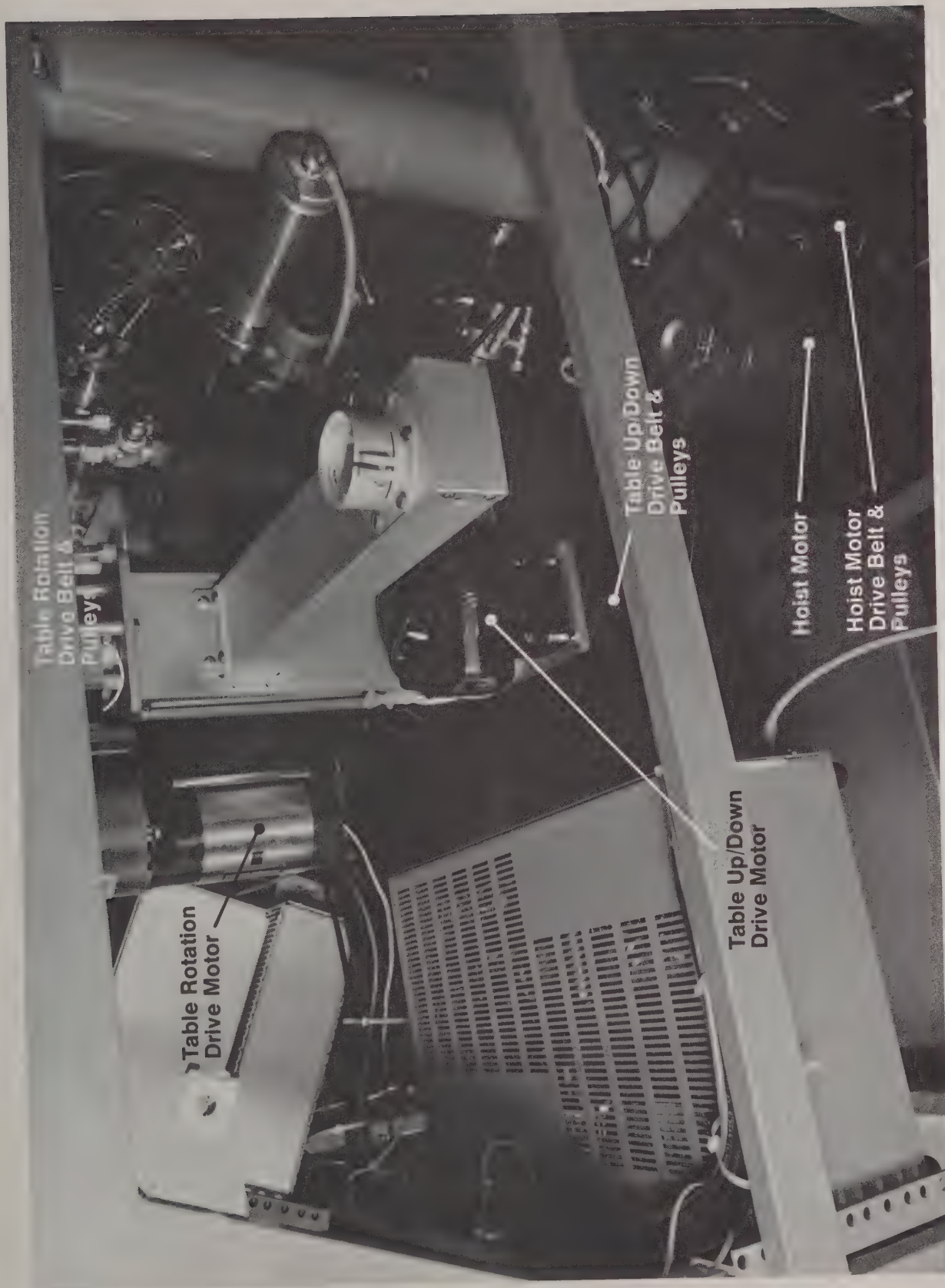
4400 Series Sputtering System Without Front Lift-Off Panels



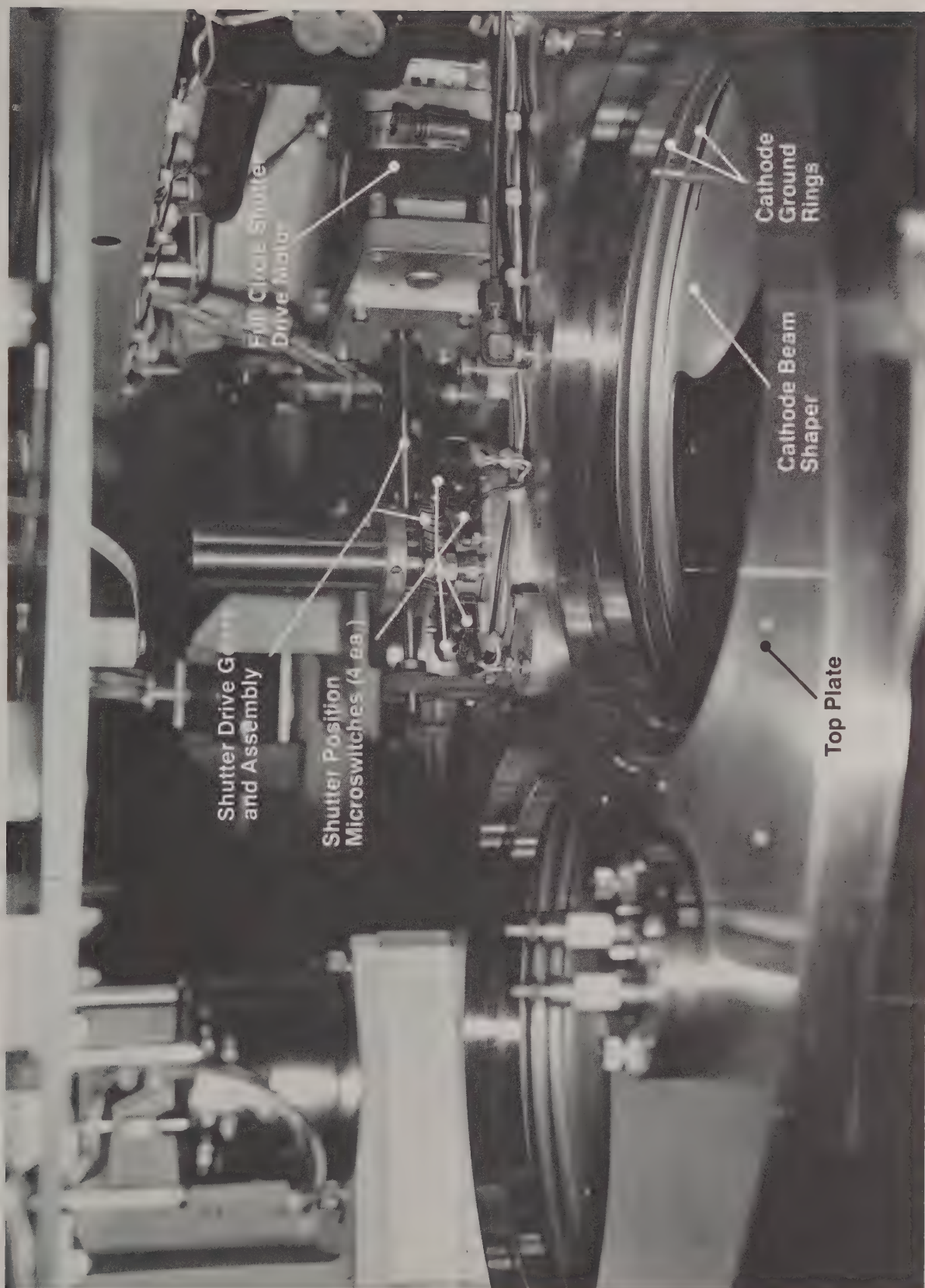
Load Lock Chamber



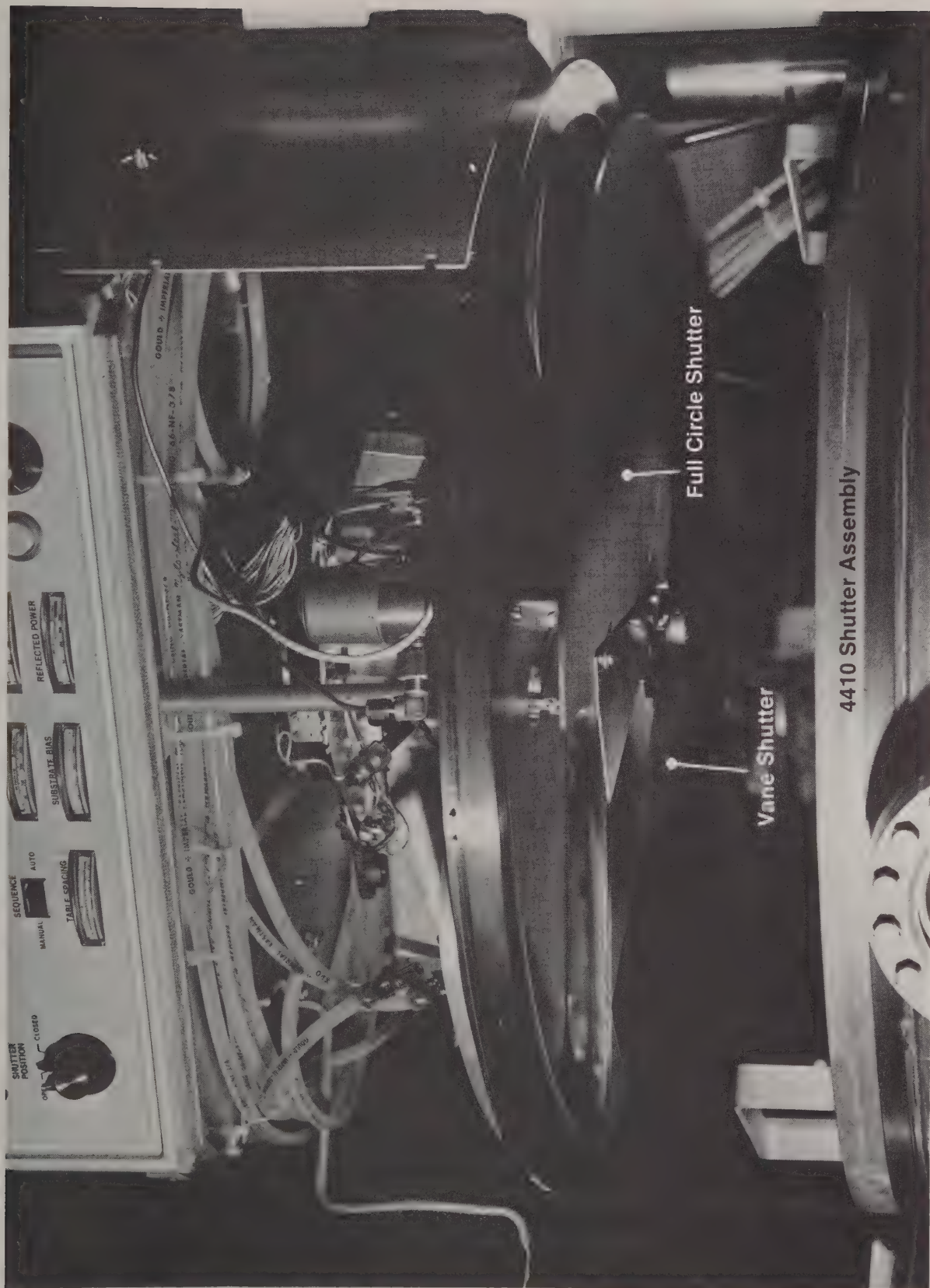
Sputtering System Vacuum Chamber And Table Assembly



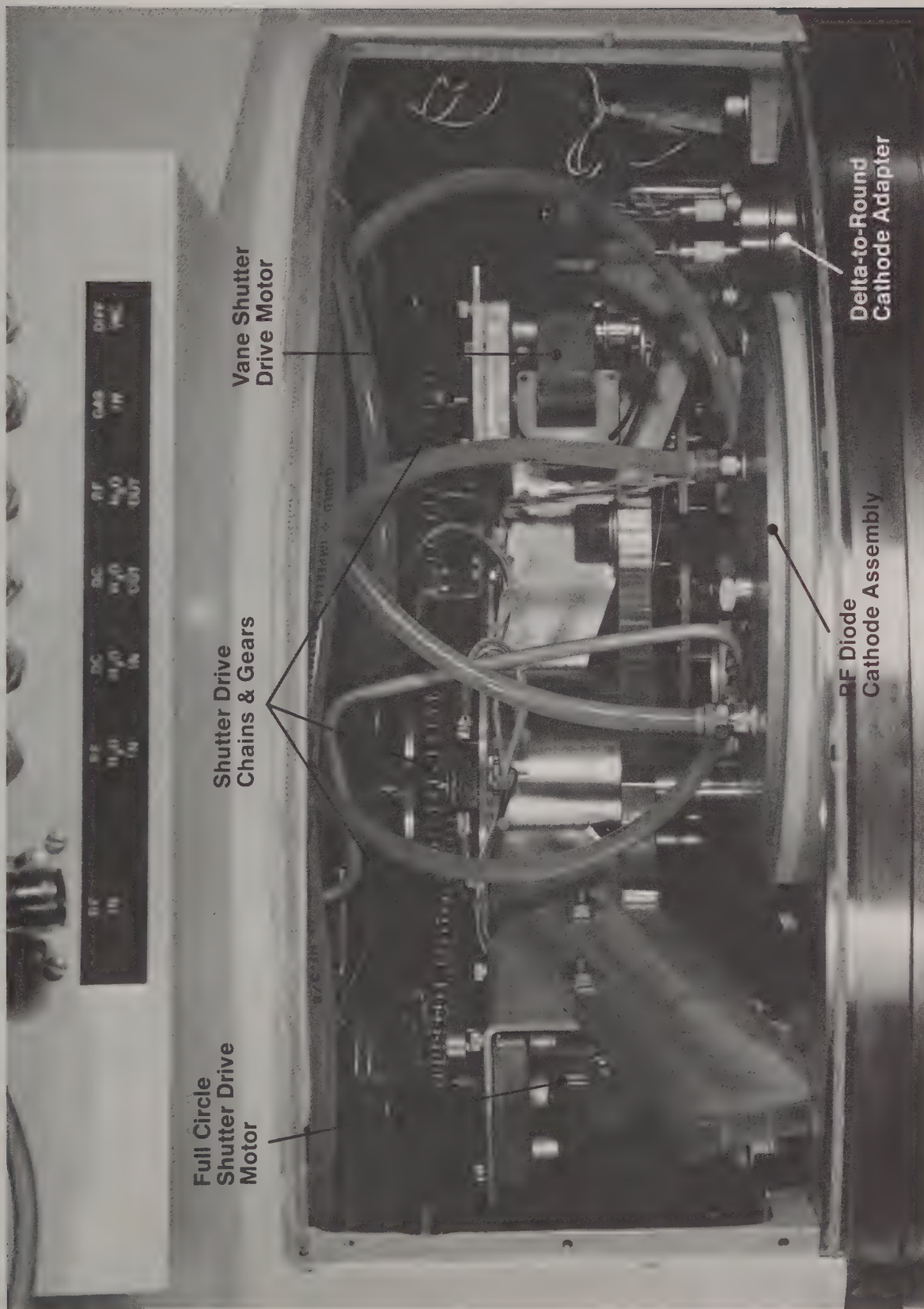
Vacuum System Main Frame



4400 Sputter Module (Inside View of Top Plate)



4410 Shutter Assembly



4410 Sputter Module (Inside View of Top Plate)

AUTO PUMPDOWN CONTROL

Operates pumps and valves via the power distribution system. When the control is in a fully automatic mode with two-hand pushbutton operation, it sequences valves for pumpdown, venting, or gas inlet for sputtering operation. The control also operates in a fully interlocked mode. The latter is useful for operating the system during maintenance periods when various valves might be operated out of normal sequence or contrary to the usual sequence. To operate in the interlock defeat mode, both the front panel key and rear panel toggle switches must be put in this mode.

Operation:

The controller has three modes of operation:

MANUAL—for servicing only. Front panel Key Switch in **MANUAL** position and switch on the rear panel in **INTERLOCK DEFEAT** position. In this maintenance mode all valves are driven directly with no interlocking.

WARNING

Do not use this mode during normal operation! Always keep the rear panel switch in **NORMAL OPERATION position!**

INTERLOCKED MANUAL—for manual system operation. Key switch is in **MANUAL/INTERLOCKED** position. Valves are driven by switches, but work only if the switches are thrown in the right sequence and if proper pressures are established. No time delays are used in this mode.

AUTO—for automatic operation. Key Switch is in **AUTO** position. In this mode all operations are fully automatic with interlock signals, pressure levels and time delays. The **AUTO** mode has five possible conditions:

1. **VENT**—the high vacuum valve is closed, roughing valve is closed and vent valve is open. The **GAS** pushbutton can be used to interrupt venting.
2. **PUMP**—the foreline is closed, vent valve is closed, and if the hoist is down, the roughing valve is open. The chamber is pumped down to the preset crossover pressure (**TRIP**), then the controller goes into the standby condition. **GAS** pushbutton can be used to interrupt pumping.
3. **STANDBY**—roughing valve is closed, foreline valve is open and the high vacuum valve is open if chamber pressure is below the **TRIP** point. Chamber pressure is shown on T.C. Gauge Meter and the crossover pressure (**TRIP**) can be adjusted from 10 to 500 μ .
4. **GAS**—the high vacuum valve must be open, the optional throttle valve is closed and the gas valve is open. **PUMP** pushbutton shuts off the gas.
5. **LOAD LOCK ROUGHING**—if the system has a load lock and only one mechanical pump, foreline and chamber roughing valves are closed during pumping down the sideloader. The high vacuum valve stays open. Gas is shut off during load lock pumping.

To activate any modes, pushbuttons are used simultaneously with the **START** button.

INTERLOCKS AND LOGIC CONDITIONS

Interlocks:

1. High vacuum pump water flowing.
2. Turbo at speed (systems with turbo only).
3. Hoist is down.
4. Load lock roughing (system with sideloader and only one mechanical pump).
5. Load lock at ATM.

Logic Conditions

1. Foreline valve or roughing valve can be open only if the mechanical pump is on.
2. Foreline and roughing valves cannot be open simultaneously.

3. Vent valve can be open only if roughing and high vacuum valves are closed and the load lock is at ATM.
4. High vacuum pump can be on only if the mechanical pump is on and cooling water is flowing.
5. High vacuum valve can be open if the foreline valve is open, high vacuum pump is on (at speed if turbo is used) and chamber pressure is below TRIP.
6. Gas valve can be opened if the high vacuum valve is open and optional throttle valve is closed.
7. Roughing valve can be open if the vent and foreline valves are closed and the hoist is down.

ADJUSTMENTS

The thermocouple gauge is set for ZERO with a small screwdriver through the front panel access hole labeled ZERO. This should be done only when the sensor is at a vacuum of at least 10^{-4} Torr.

A hole labeled TRIP sets the point of crossover from the roughing pump to the high vacuum pump. This crossover should be set between 50 to 200 microns depending on the reactivity of target materials and the type of high vacuum pump use.

The liquid nitrogen timer adjusts time between fills from 3 minutes to 2 hours. Increase the time by turning clockwise.

LN₂ Controller

Perkin-Elmer's LN₂ Controller consists of a level sensor, control panel, and electric solenoid LN₂ valve.

The level sensor is a bellows pressure switch with a capillary tube that is evacuated, backfilled with gaseous nitrogen, and pinched off. This switch operates when the capillary is emersed in LN₂.

The LN₂ Control is included in the Automatic Pumpdown Control. The only adjustment on this control is the interval between LN₂ sensings. Once the LN₂ vessel is full, the sensor switch closes.

LOCK CONTROL

Load Lock Controller

GENERAL

The 4400 Production Sputtering System Load Lock permits loading and unloading of substrate wafers while the sputtering chamber is isolated from the atmosphere. Use of the Load Lock assures high repeatability without requiring a new target cleaning cycle before processing each batch. Higher production rates result from the elimination of repeated target cleaning operations as well as from the shorter time required to transfer from atmosphere to sputtering pressure.

In the standard configuration, the Load Lock is mounted at the left of the sputtering chamber and rests on top of the cabinet supporting the main pumping system.

The Load Lock accepts a 23½-inch diameter wafer pallet which typically holds 30 3-inch diameter wafers. To load a pallet of substrates, the operator places the pallet on the self-aligning elevator, depresses both Lock door switches located on the narrow panel directly beneath the Lock, and closes the Lock door.

NOTE

Keep the switches depressed until the drive motor stops. Limit switches prevent over driving but full limit drive must occur or the load cycle will not continue. Subsequent steps in the sequence can be controlled by automatic control circuits in the Lock Control or by the operator using the control switches in the MANUAL mode. The automatic/manual mode choice is made by the operator.

The automatic load sequence operates as follows:

1. When the Lock door is fully closed, the roughing valve opens and the Load Lock is roughed to a preset trip point pressure.

NOTE

The trip point is set at any pressure level from 10 to 500 microns by a potentiometer located just below the meter on the Lock control panel.

2. The roughing valve closes, the interchamber valve door opens, and the pallet carriage transports the pallet into the processing chamber.
3. When the carriage is fully inserted, the anode/table is raised, lifting the pallet off the carriage.
4. After the table is fully elevated, the carriage retracts into the Load Lock and the interchamber valve door closes.
5. The sputtering process can now begin. The pallet is unloaded from the sputtering chamber in a reverse manner. Both the load and unload operations are described in detail in the OPERATION section.

COMPONENTS

Figure 1 illustrates the principal components of the 4400 Load Lock and their relation to the processing chamber. These components include:

LOCK DOOR—Pallets filled with substrates are loaded into and removed from the Load Lock through this door. When closed, the door seals the chamber while it is under vacuum.

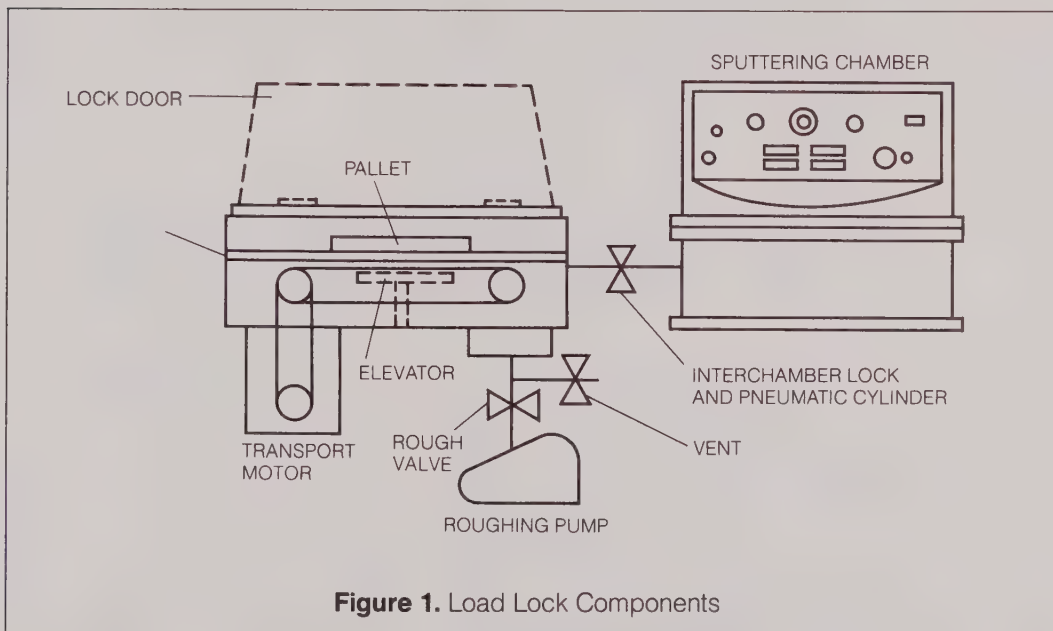
ROUGHING PUMP AND VALVE—This is a 36.7 cfm (60 m³/hr) mechanical pump, surface-area Versa-Trap™, and air-operated roughing valve. The mechanical pump will reduce Lock pressure to 50 m Torr (microns) in about 1½ minutes. For systems equipped with alternatives to the cryopump, roughing is accomplished with the same pump that backs the high vacuum pump.

VENT—The Lock chamber is vented to atmosphere through this valve before the Lock door can be opened. It is recommended that venting be done with dry nitrogen gas.

ELEVATOR AND PNEUMATIC CYLINDER—This air-operated elevator automatically rises out of the Lock chamber each time the Lock door is opened. It automatically lowers into the chamber each time the operator initiates the load sequence by closing the Lock door. This feature makes pallet handling at the Load Lock more convenient; the operator never has to reach into the Lock chamber.

TRANSPORT MECHANISM AND DRIVE—This device carries a pallet of substrates from the elevator to the anode/substrate table (LOAD operation) or from the anode/substrate table to the elevator (UNLOAD operation). A horseshoe shaped pallet carriage, riding on chain-driven friction drive wheels, is transported into or out of the sputtering chamber while carrying the pallet.

INTERCHAMBER VALVE DOOR—This valve consists of an O-ring sealed door that isolates the processing chamber while the Lock is pumped down to trip-point pressure. At the trip point, this valve door opens, allowing the transport to move the pallet into or out of the processing chamber.



CONTROLS AND INDICATORS

In addition to the mechanical elements of *Figure 1*, the Load Lock includes an electronic sequence controller which can be operated in an automatic or manual mode by selecting the desired mode with the key switch. The control panel features are described in the following tables:

Table 1. Manual Controls

Control	Function
MODE AUTO/MANUAL INTERLOCKED/MANUAL (three-position key switch)	Setting this switch in the AUTO position enables the pushbutton controls described in Table 2. Selecting the MANUAL INTERLOCKED mode enables the panel toggle switches with all interlocks functioning. Selecting MANUAL and switching the rear panel toggle switch to INTERLOCK DEFEAT permits operation of all functions independently for maintenance purposes.

WARNING

Do not leave the panel toggle switch in the INTERLOCK DEFEAT position. Inadvertant operation in this mode can result in extensive system downtime caused by venting to atmosphere or other substrate damaging conditions.

ELEVATOR UP/DOWN (two-position toggle switch)	This switch controls the elevator pneumatic cylinder. When the switch is in the UP position, the elevator rises until it meets the upper limit. When the switch is in the DOWN position, the elevator lowers until it reaches the lower limit.
LOCK VALVE OPEN/CLOSE (two-position toggle switch)	This switch controls the interchamber valve pneumatic cylinder. When the switch is in the OPEN position, the interchamber valve door opens. Conversely, in the CLOSE position the valve door closes.
CARRIAGE IN/OUT (three-position toggle switch)	This switch controls the motor that operates the transport drive mechanism. When the switch is in the IN position the drive transports the pallet carriage from the Lock into the chamber. In the OUT position the carriage is driven from the chamber into the Lock. The interchamber valve door is interlocked with the carriage IN/OUT switch. However, the friction drive prevents damage even if the interlock defeat mode is used. The transport mechanism can be stopped at any intermediate point by setting this switch to the center position.

Table 1. Manual Controls (Continued)

Control	Function
PALLET UP/DOWN	This switch controls the motor that drives the anode/substrate table up or down. With the switch in the UP position, the table is raised to the upper limit. When the table reaches the upper limit it begins rotating. With the switch in the DOWN position, the table is caused to lower. (IF GAS IS ON)

CAUTION

Care must be exercised when operating in the manual mode so that table and carriage locations are kept clearly in mind. If the pallet is on the table and the table is lowered, the carriage can be transported into the chamber over the pallet. Raising the table would lift the carriage off the transport mechanism and it might be necessary to vent the system to make the transport mechanism operable again.

IMPORTANT

ROUGH VALVE OPEN/CLOSED	This switch controls the Lock roughing valve. When the switch is in the OPEN position the valve opens and in the CLOSED position the valve closes.
VENT VALVE OPEN/CLOSED	This switch controls the Lock vent valve. The OPEN and CLOSED positions refer to the vent valve being open or closed.
PRESSURE ZERO/TRIP	These controls are potentiometer adjustments located just below the Lock pressure meter. The ZERO is set by first roughing the Lock, then opening the interchamber valve door to permit high vacuum pumping of the Lock. When the Lock pressure is 1×10^{-4} Torr or lower, set the meter to read zero using the potentiometer labeled ZERO. To set the pressure at which the Lock roughing ends and the interchamber valve door opens, rough the Lock chamber to the desired pressure then adjust the potentiometer labelled TRIP until the trip indicator illuminates. This trip point may be set anywhere between 10 and 500 microns.

Table 2. Automatic Controls and Indicators

Control/Indicator	Function
LOAD	This switch, when depressed together with the START button, initiates an automatic load cycle. If the Lock door is lowered in the AUTO mode, the load cycle is automatically initiated and it is not necessary to depress this button.
UNLOAD	This switch, when depressed together with the START button initiates an automatic unload cycle.
STANDBY	The STANDBY switch serves two functions. If the STANDBY button is depressed (together with the START button) during Lock roughing in the LOAD cycle, the roughing will be discontinued and the load cycle will not continue beyond that point. If the STANDBY button is depressed (together with the START button) following an UNLOAD command, the unload cycle will be performed until the pallet has been withdrawn into the Lock and the inter-chamber valve door closed. The Lock will not be vented to atmospheric pressure. In both standby modes, the processed substrates are stored under vacuum.

NOTE

To terminate the STANDBY command, use both the LOAD and START buttons or both the UNLOAD and START buttons to complete the load or unload cycle, respectively.

LOCK AT ATM (Indicator)	This indicator is located on the water flow switch/Lock door actuator panel just below the Load Lock. When illuminated, it indicates the Lock is at atmospheric pressure.
LOADED (Indicator)	This indicator is located on the Lock controller panel above the LOAD, STANDBY, and UNLOAD buttons. When illuminated, it indicates that a load cycle has been completed and there is a pallet in the chamber.

NOTE

This indicator functions only if the automatic load sequence has been used.

OPERATION

Detailed instructions for operating the 4400 Load Lock in the manual and automatic modes are given separately below. Operators who have little or no knowledge of Load Lock functions should become thoroughly familiar with this and the preceding sections of the manual before operating the Lock.

Manual Operating Procedure

Ignore any of the following instructions that have already been completed and pass on to the next instruction in the sequence.

Manual Load Sequence

1. Put the Lock controller key switch in the MANUAL INTERLOCKED position.
2. Open the Lock door using both actuating switches.
3. Set the CARRIAGE switch to OUT.
4. Set the ELEVATOR switch to UP.
5. Set the LOCK VALVE switch to CLOSED.
6. Set the PALLET switch to DOWN.
7. Place the pallet on the elevator.
8. Set the ELEVATOR switch to DOWN. This will lower the pallet onto the carriage.
9. Close the Lock door using both actuating switches. Be sure the motor drive stops by itself.
10. Set the VENT VALVE switch to CLOSE.
11. Set the ROUGH VALVE switch to OPEN. This will cause the mechanical pump to rough the Load Lock.
12. Pump the Lock until the trip point is reached. This is indicated by the TRIP light on the Lock Control panel.
13. Set the ROUGH VALVE switch to CLOSE. This will terminate roughing and isolate the mechanical pump from the Load lock. (Open Foreline valve if pumped by Diffusion or Turbo pumps).
14. Set the LOCK VALVE switch to OPEN. This causes the interchamber valve door to open.
15. Set the CARRIAGE switch to IN. This causes the pallet transport mechanism to move the carriage into the sputtering chamber.
16. Set the PALLET switch to UP. The anode/table will rise and pick up the pallet from the carriage.
17. Set the CARRIAGE switch to OUT. The carriage then withdraws into the Load Lock.
18. Set the LOCK VALVE switch to CLOSE. The interchamber valve door closes to isolate the Lock chamber from the processing chamber.

Manual Unload Sequence

1. If the TRIP indicator is not illuminated, set the ROUGH VALVE switch to OPEN to reduce the Lock pressure to the trip point.
2. Set the ROUGH VALVE switch to CLOSED.
3. Set the LOCK VALVE switch to OPEN to open the interchamber valve door.
4. Set the CARRIAGE switch to IN.
5. When the carriage indicator labelled IN illuminates, set the PALLET switch to DOWN.
6. Set the CARRIAGE switch to OUT after the pallet is completely lowered onto the carriage.
7. When the carriage indicator labelled OUT illuminates, set the LOCK VALVE switch to CLOSED.
8. Set the VENT VALVE switch to OPEN.
9. When the LOCK AT ATM indicator illuminates, the Lock door may be opened by depressing both actuator switches.
10. Set the ELEVATOR switch to UP.

Automatic Operating Procedure

The following conditions must be met before using the Load Lock in the automatic mode.

1. The transport carriage must be in the OUT position.
2. The interchamber valve door must be closed.
3. The Lock chamber must be vented to atmosphere.
4. The Lock door must be open.
5. The processing chamber must be under vacuum with the high vacuum valve open.
6. The key switch on the Lock control panel must be set to AUTO.

Automatic Load Sequence

1. Place the substrate pallet on the elevator.
2. Use both door actuating switches to close the Lock door. The elevator will automatically lower the pallet onto the carriage and the LOAD indicator will illuminate on the Lock control panel. Allow the Lock door drive to run against the limit switch and stop of its own accord.
3. The LOADED indicator will illuminate when the load sequence is complete.

NOTE

If the operator presses the STANDBY button together with the START button, the Lock will continue to be roughed to the trip point pressure but will proceed no further with the load cycle. To disengage STANDBY, depress the LOAD button together with the START button and the load sequence will proceed to completion.

Automatic Unload Sequence

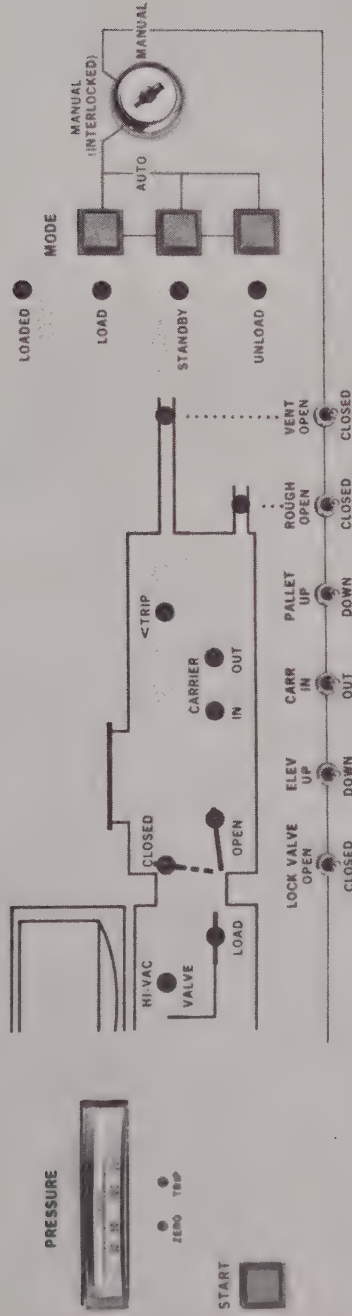
The unload operation typically follows a load operation, and therefore, the Lock chamber is under vacuum with the roughing valve and interchamber valve door both closed. The unload sequence consists of the following steps.

1. Press the UNLOAD button together with the START button. If the Lock pressure has risen higher than the trip point pressure, the roughing valve will open and the Lock pressure be reduced to the trip point.
2. The unload sequence is automatically executed including venting the Lock to atmospheric pressure.
3. When the LOCK AT ATM indicator illuminates, the Lock door can be opened by depressing both door-actuating switches. The vent valve will automatically close and the elevator will rise to its upper limit.

NOTE

If the operator presses the STANDBY button together with the START button after the unload sequence has been activated, the unload sequence will proceed except that the Lock chamber will not be vented to atmospheric pressure. The processed substrates will be stored under vacuum.

ULTEK LOCK CONTROL



DIGITAL GAUGE CONTROL

(Includes Wide Range Gauge Control Unit)

GENERAL INFORMATION

Perkin-Elmer's Digital Gauge Control II provides accurate indication of pressure in the 2×10^{-11} Torr (or gauge X-ray limit) to 2×10^{-1} Torr range. An ionization gauge is used to cover the 2×10^{-11} Torr to 1×10^{-2} Torr range in the basic DGC II. A thermistor gauge (thermal conductivity type) measures pressures in the 1×10^{-3} Torr to 2×10^{-1} Torr range (1 to 200 millitorr or microns).

Perkin-Elmer's Wide Range Gauge Control provides accurate indication of pressure in the 2×10^{-11} Torr (or gauge X-ray limit) to the 1 Torr range. An ionization gauge is used to cover the 2×10^{-11} Torr to 1×10^{-1} Torr range in the basic WRG. A thermistor gauge (thermal conductivity type) is included to measure pressures in the 1×10^{-3} Torr to the 1 Torr range (1 to 1000 millitorr or microns).

Operation

CONTROLS AND INDICATORS—All controls and indicators required for both DGC and WRG operation are located on the front panel. The function of each control and indicator is described in Table 1.

Table 1. Control and Indicator Functions

Name	Reference Designation	Function
FUNCTION Switch:	S1	
OFF		De-energizes instrument.
ST1		Connects to station 1 thermistor gauge.
ST2		Connects to station 2 thermistor gauge.
EXT. GAUGE	*	Connects to ION GAUGE receptacle for wide range Bayard-Alpert gauge tube.
EMISSION		Provides three multiplier emission indications.
DEGAS		75 W of degas power for resistance heating of the grid.
FILAMENT	S3	Switch turns ionization gauge tube filament ON and OFF.
Pushbutton		Indicator lamp is ON when emission is at correct value. Indicator lamp is OFF when filament is off or emission is incorrect.
Switch/Indicator		
Five-Digit Display	V1	First display segment (V1) indicates a negative signal by showing a minus sign. This segment will also display a 1, when applicable, during hold modes, emission check, and first digit segments during thermistor gauge operation. This display also indicates second and third segments of pressure or emission in units and tenths, respectively.
	V3	Fourth and fifth display segments indicate exponent of negative powers of ten.

*Only on Wide Range Gauge Control

Table 1. Control and Indicator Functions (Continued)

Name	Reference Designation	Function
Display Multiplier	V2	Indicates X10 in Torr readings and is disabled when switched to functions other than pressure measuring mode.
MODE Switch:	S2	
ADJ-A		N/A
ADJ-B		N/A
AIR-HOLD		If FUNCTION switch is in ST1 or ST2 positions, the thermistor gauge will give an air-calibrated pressure indication. If the FUNCTION switch is in one of the emission positions, automatic range switching is disabled and the WRG or DGC will be held in existing operating range.
ARGON-AUTO		If the FUNCTION switch is in ST1 or ST2 positions, the thermistor gauge will give an argon-calibrated pressure indication. If the FUNCTION switch is in one of the emission positions, pressure ranges will switch automatically with the exponent portion of the display indicating the existing range.
ZERO		Allows the display to be used to zero the electrometer circuitry.
EMISSION ZERO Electrometer	R2	Permits the electron emission to be set. Located at the right end of the front panel, this adjustment is used to calibrate the DGC or WRG electrometer circuitry with the MODE switch in the ZERO position.
ZERO/ST1-ST2	R4	These adjustments allow the zero pressure calibration of the two thermistor gauges. ST1 ZERO is adjustable with the FUNCTION switch in the ST1 position and ST2 ZERO is adjustable when the FUNCTION switch is in the ST2 position.
EMISSION (screwdriver adjustment)	R3	Used to set emission control level with MODE switch in the EMISSION position in both the DGC and WRG.
SET POINT ADJ:		
PT. A		N/A
PT.B		N/A

NOTE

The control panel for each model includes only those controls and indicators which apply to the features included in that model although holes and silkscreening are provided for field retrofit of any option. "N/A" designation above refers to options not used in this configuration.

OPERATING PROCEDURES

Ionization Gauge Pressure Measurement

All front panel controls that are associated with operation of the ionization gauge control are labeled with brown lettering.

Ionization Gauge Tube Emission Adjustment

The following procedure should be performed before initial operation or whenever changing to a gauge tube with an emission current rating different than the tube used previously.

NOTE

The emission adjustment sets an internal reference level and the adjustment procedure should be performed before the gauge tube is connected. This will safeguard against inadvertent damage to the gauge tube.

1. Set MODE switch to EMISSION.
2. Set FUNCTION switch to any EMISSION position (not DEGAS).
3. Turn Emission screwdriver adjustment until display indicates the emission value given in the tube manufacturer's specification. For an emission of 10 mA (nominal emission value for most tabulated gauges) the display should read 10.0.

When the ionization gauge is operated, the actual emission will be the value seen on the display when the MODE switch is in the EMISSION position times the multiplier given by the FUNCTION switch position. For example, if the display is set to read 10.0 and the FUNCTION switch is set at the 0.1 position, the actual emission is $10.0 \times 0.1 = 1.0$ mA. If an emission of 10 μ A (0.01 mA) is desired, the display should be set to read 1.0 when the MODE switch is in the EMISSION position. When the FUNCTION switch is set at the 0.01 position, the actual emission in the gauge tube will be $1.0 \times .01 = 0.01$ mA or the required 10 μ A. When the FUNCTION switch is in the EXT. GAUGE position, a multiplier of 0.01 is used.

Zero Adjustment

The following procedure is used to zero the internal pressure measurement circuitry. This procedure should be performed whenever the digital display indicates a negative (–) condition or the units and tenths digits are not both zero when the MODE switch is in the ZERO position.

1. Set MODE switch to ZERO.
2. Set FUNCTION switch to the 1 EMISSION position.
3. Insert screwdriver into slotted potentiometer drive behind the hole marked ZERO (righthand end of front panel) and adjust until the display indicates 0.0×10^{-11} Torr. The first segment must not display a minus sign (–). If the FUNCTION switch is set at .1 EMISSION, the display should read 0.0×10^{-10} Torr and at 0.01 EMISSION, the display should read 0.0×10^{-9} Torr.

Operating Procedure

NOTE

Because of the automatic filament protection circuit, the unit will not allow the ionization gauge tube filament to remain on until the pressure is below 10×10^{-2} Torr (refer to Table 2). The thermistor gauge can be used to verify an adequately low pressure before attempting to turn on the ionization gauge filament.

Table 2. Maximum Indication Vs. Function Switch Emission Settings

		Function Switch Emission Settings							
		Ext. Gauge		0.01		0.1		1	
		Auto	Hold	Auto	Hold	Auto	Hold	Auto	Hold
DESIRED OPERATING RANGE (Torr)	10 ⁻²	10.0	10.0	**	**	**	**	**	**
	10 ⁻³	—	18.0	10.0	10.0	**	**	**	**
	10 ⁻⁴	—	18.0	—	18.0	10.0	10.0	**	**
	10 ⁻⁵	—	18.0	—	18.0	—	18.0	10.0	10.0
	10 ⁻⁶	—	18.0	—	18.0	—	18.0	—	18.0
	10 ⁻⁷	—	18.0	—	18.0	—	18.0	—	18.0
	10 ⁻⁸	—	18.0	—	18.0	—	18.0	—	18.0
	10 ⁻⁹	—	18.0	—	18.0	—	18.0	—	18.0
	10 ⁻¹⁰	*	*	*	*	—	18.0	—	18.0
	10 ⁻¹¹	*	*	*	*	*	*	—	18.0
Filament Shut-Off Points Vs. Digital Readout									

*Instrument will provide a more accurate indication at this pressure with higher EMISSION multiplier settings.

**Filament will not remain energized at this pressure with this power setting.

Degas Procedure

Both models have RH-type degas and switching to DEGAS with the FUNCTION switch causes a current of about 10 A to flow through the helical grid which soon becomes incandescent. For most applications, the radiation from the hot grid is sufficient to degas the rest of the tube. For ultrahigh vacuum, the tube should be baked with the remainder of the system.

During resistance heating (RH) degassing, pressure readings can be made while the gauge is degassing. This makes it convenient to judge the length of degassing time. Initially, the pressure indication will rise rapidly and then, after a short period, will return to a reading slightly higher than the original. As the radiation from the grid heats the rest of the tube, the pressure will slowly rise again. After several minutes, the pressure will level off, and then begin to slowly decrease. When the second decrease in pressure is observed, degassing is substantially complete. High pressure (about 1×10^{-5} Torr) can oxidize the molybdenum grid and should be avoided.

Thermistor Gauge Pressure Measurement

All front panel controls that relate to thermistor gauge operation are labeled with orange lettering. Note, particularly, the dual function positions of the MODE switch. When the WRG or DGC is controlling an ionization gauge, the black letter mode is functional but when it is controlling a thermistor gauge, the orange letter mode is functional.

Zero Adjustment

This procedure is used to balance the thermistor gauge measurement bridge when vacuum system pressure is low (5×10^{-4} Torr or lower).

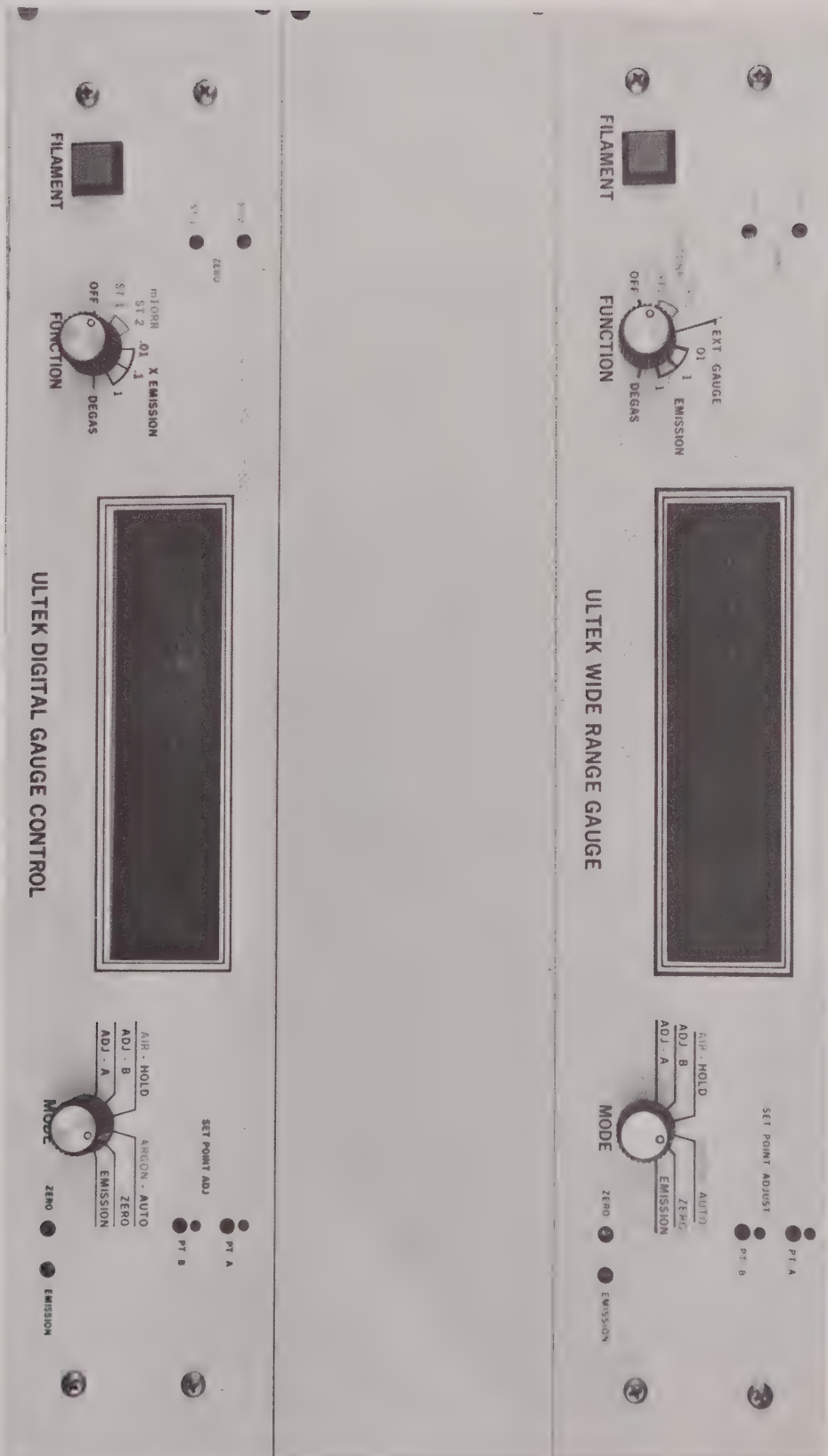
1. Set the FUNCTION switch in the ST1 position.
2. Allow the instrument to stabilize by operating for at least 5 minutes and reduce pressure in the vacuum chamber to 5×10^{-4} Torr or lower.
3. Insert a screwdriver into the slotted potentiometer drive behind the hole marked ZERO ST1 in orange lettering (left-hand end of the front panel) and adjust until the display indicates 00 mTorr. The minus (—) sign in the first display segment should not be illuminated.

4. Set the FUNCTION switch in the ST2 position.
5. Insert the screwdriver into the slotted potentiometer drive behind the hole marked ZERO ST2 in orange lettering (adjacent to the hole used in Step 4) and adjust until the display indicates 00 mTorr. The minus (–) sign in the first display segment should not be illuminated.

The thermistor gauge circuitry has now been balanced.

The following table shows the different switch positions necessary on both the DGC and WRG during Hi-Vac and "Gas-On" deposition or etch modes.

Table 3. Gauge Switch Positions			
	FILAMENT SWITCH	FUNCTION SWITCH	MODE SWITCH
<i>DGC</i>			
Gas off (Hi-Vac)	ON	.01	AUTO
Gas On	OFF	ST1	AUTO
<i>WRG</i>			
Gas off (Hi-Vac)	ON	Ext. Gauge	AUTO
Gas On	ON	Ext. Gauge	AUTO

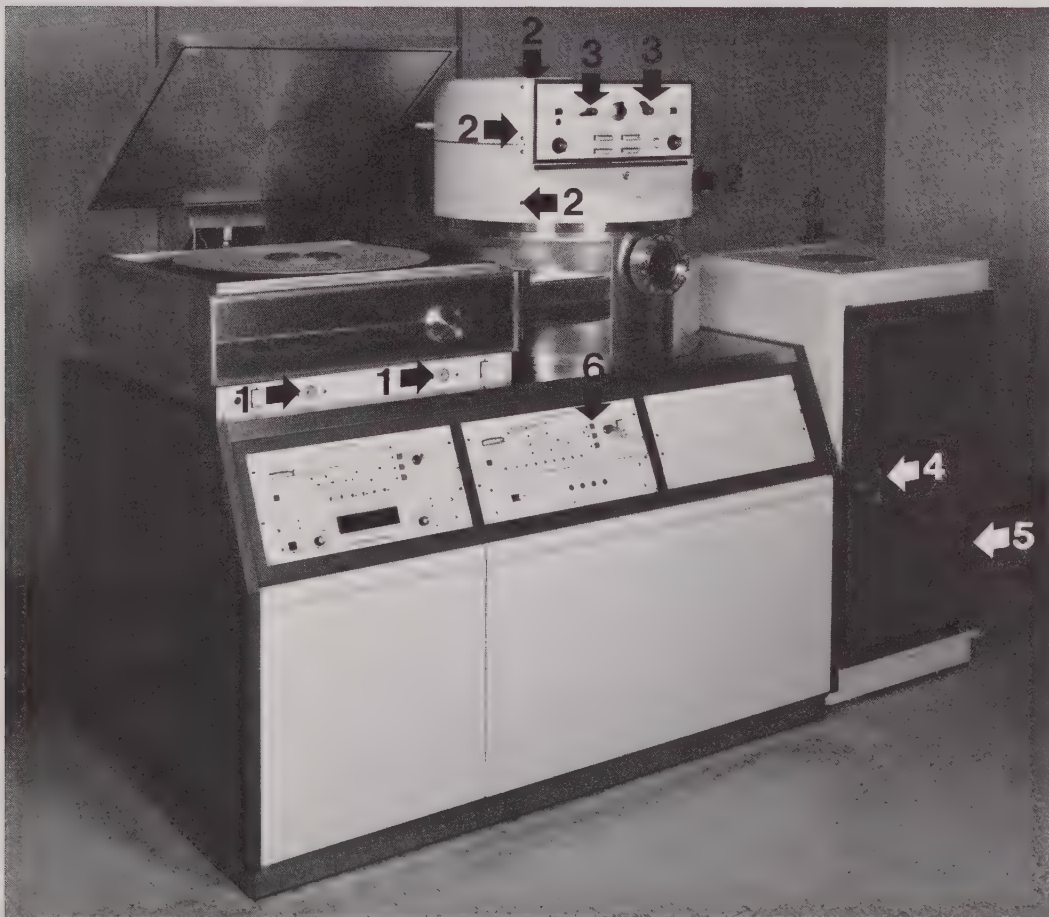


Wide Range Gauge and Digital Gauge Control

SAFETY INTERLOCK SWITCHES

The safety interlock switches are provided as a standard feature incorporated into all systems. They ensure operator and system protection during RF and DC deposition and etch modes. If any of the following interlocks are not properly activated, the RF and DC power will not turn on.

1. WATER FLOW SWITCHES—Adequate water flow for cooling must be provided.
2. SPUTTER MODULE COVER SWITCHES—All covers must be in place on the sputter module.
3. MODE AND TARGET SELECTOR SWITCHES—Both switches must be in their proper location detent for circuit contact.
4. RF POWER SUPPLY DOORS—Both front and rear doors must be in place and closed.
5. RF POWER SUPPLY POWER—The RF Power Supplies main power circuit breaker must be on.
6. GAS MODE ON —The gas ON mode must be met to supply gas in the chamber to support a plasma.



4400 Series System with Safety Interlock Switch Detail

RF POWER SUPPLY

GENERAL INFORMATION

The RF power generators consist of a crystal-controlled exciter section, a one-stage linear power amplifier, and a power supply capable of delivering all necessary operating voltages. The generator delivers its rated output for continuous-duty operation.

Complete overload protection, remote operation, and casters, are standard.

Harmonic and other spurious radiation is reduced in accordance with FCC regulations and OSHA standards.

The power tube develops high temperatures during operation, so the generator should be situated where it can be properly cooled. The equipment should be placed far enough away from any wall, furniture, or surface to allow an adequate flow of cool air through the rear vent. Avoid placing any objects on the ventilating grill on top of the generator.

Operating Cautions

CAUTION

The operating voltages inside the generator are lethal. Do not operate the generator with any of its doors or panels removed unless you observe the utmost caution!

Never operate the generator without connecting the RF output to the sputter head or a dummy load. All covers and doors must be securely in place for safe operation. Do not defeat interlocks—they ensure your safety. Always allow about 5 minutes operation with the RF off before turning the generator off. This allows the power tube to cool and prolongs tube life.

OPERATING INSTRUCTIONS

1. Turn on generator circuit breaker (located on front door).
2. Wait 90 seconds for tubes to warm up.
3. Push RF ON button (located on sputter head).



RF Power Supply

DC MAGNETRON POWER SUPPLY

(Programmable Mag. Supply 5 and 10 kW)

The D C Magnetron power supply regulates its output power to a constant V.A. Product as programmed into the unit by either the manually operated control pot located on the front panel or by use of the BNC Connector located on the Control Box rear panel, J1.

The external input (J1) is selected by the PROGRAM/MANUAL rocker switch located on the front panel of the Control Box.

The system was designed primarily to provide power to the Perkin-Elmer "DELTA-SOURCE" sputter head.

The toggle switch on the rear panel, labeled ELEVATE for one position and GROUND in the other position, *must* be placed into the "Elevate" position when the "Delta Source" is to be used. The "Ground" position of the toggle switch is merely for testing or using the supply for more conventional uses and standard targets (Round DC magnetron). Never move this switch while power supply is operating!

NOTE

The "Grounding Stud" (near the switch) must be connected to the system sputter head with large wire (low resistance) as short in length as possible. Output currents to the sputter head flow through the grounding wire (strap) as well as the other two output cables. (Hence, the 3rd terminal of the above mentioned 3-terminal system).

Three light-emitting diodes are located in the front panel control for reading out the conditions appearing at the output terminals of the supply. They are the following:

SHORT (short ckt. appearing across the output)

OPEN (open ckt. appearing at the output)

ERROR (appearing anytime the output V.A. product does not/or cannot match the programmed level, either for Manual or Prog. inputs).

Further explanation of the ERROR Detecting L.E.D.

This detector measures the differential error between the V.A. product appearing into the Plasma Load and that linear input D C voltage used for providing the input programming D C level.

The error may light briefly during the changing of programming levels. The error will in fact light anytime the supply begins to "current limit" and/or "Voltage Limit." These two conditions would occur when "Plasma-impedance" reduces to either too low or too high a value.

To operate the DC Magnetron power supply, the following procedure should be followed (after the system is set-up and ready).

1. Turn main power circuit breaker ON .
(Located on the main power supply chassis).
2. Turn power adjust pot to zero power (full ccw).
3. Program/manual rocker switch to MANUAL .
4. Select required deposition time on timer.
5. Press the "Continuous" button to turn DC power on and slowly turn "Power Adjust" knob up (cw) to desired power level. The power is read in kilowatts on the digital meter.
6. Open the shutter to the proper target position being deposited from ("Shutter Position" switch is located on the sputtering module).
7. As soon as the shutter is fully open, (the shutter rotation light goes out) press the "Time" button. This will then activate the deposition timer and when it times out the D C power will be shut off automatically.
8. After the deposition is completed, always turn the "Power Adjust" knob back to zero power (full ccw).

Should a problem arise during a deposition, the STOP button can be pushed to turn the DC power off. The digital volt meter on the front panel indicates target bias voltage.

The design load value for 5 kW units is 30-70 ohms.

The design load value for 10 kW units is 20-70 ohms with current limit set to limit into 25 ohms.

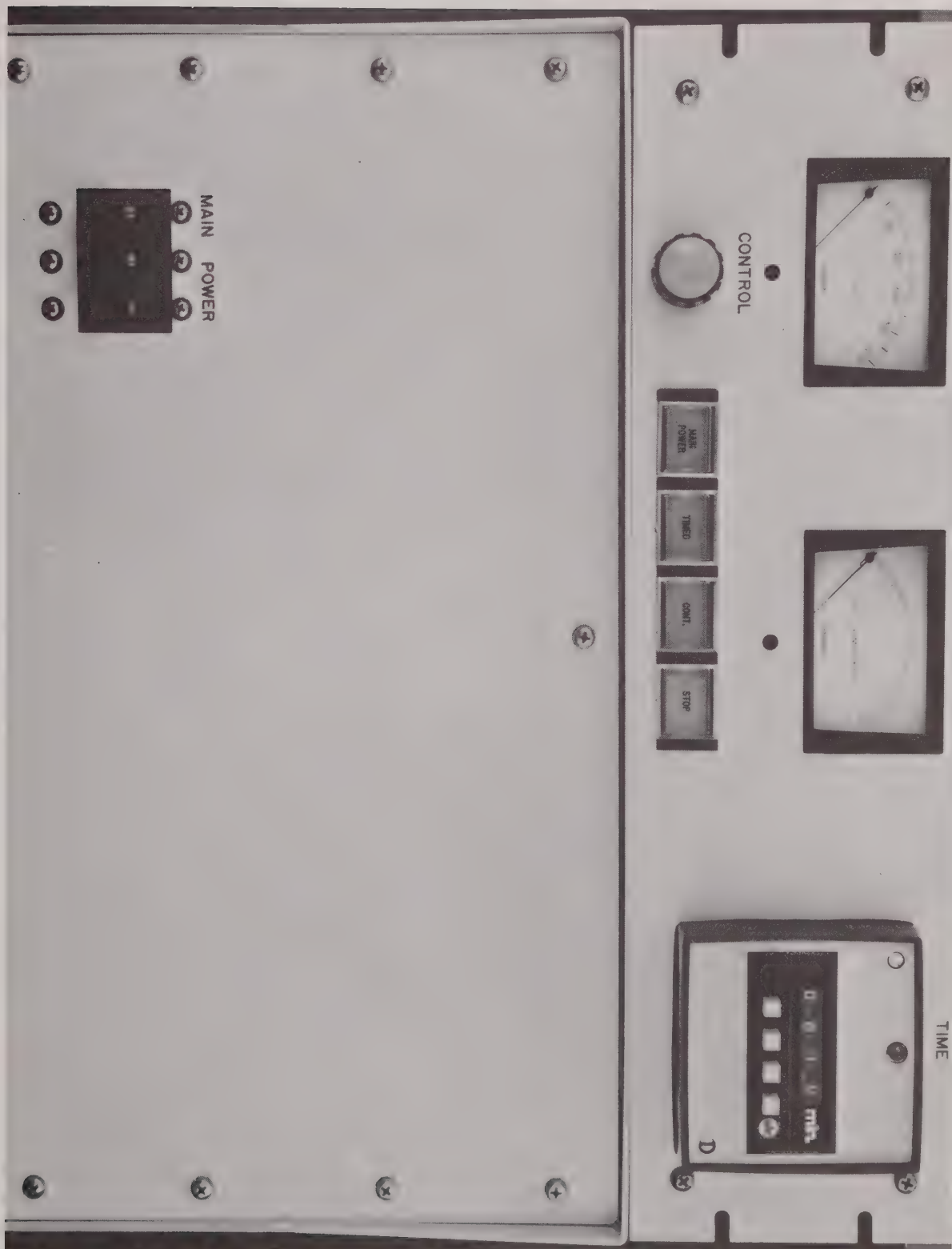
The error lamp will light anytime the programming D C voltage is at zero or near zero v.d.c.

The error lamp will remain lighted until the output V.A. product increases from around zero to approximately 80-100 watts as read on the Wattmeter on the control panel.

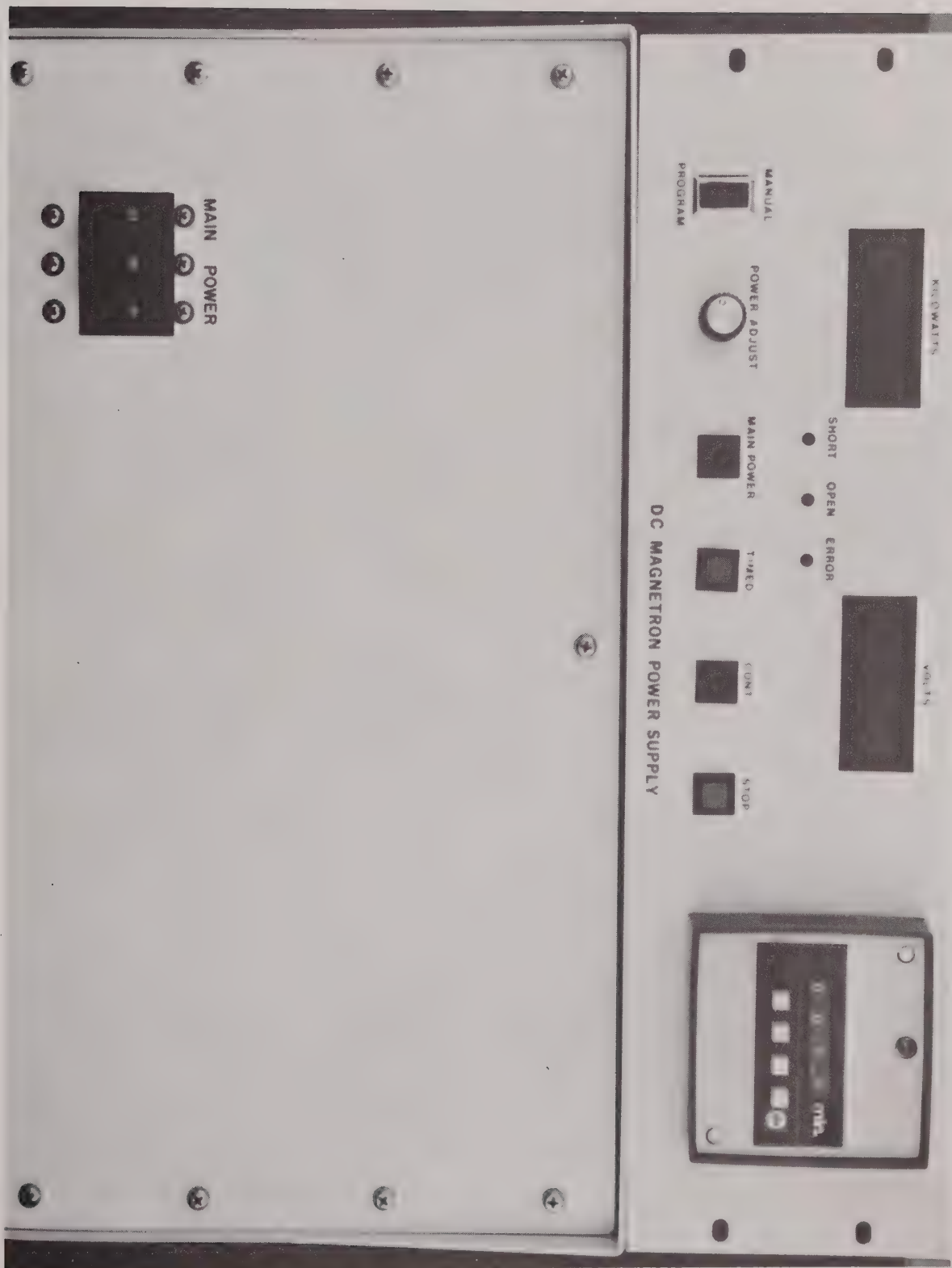
The error lamp will also light anytime an arcing condition within the sputtering head occurs for an appreciable time.

NOTE

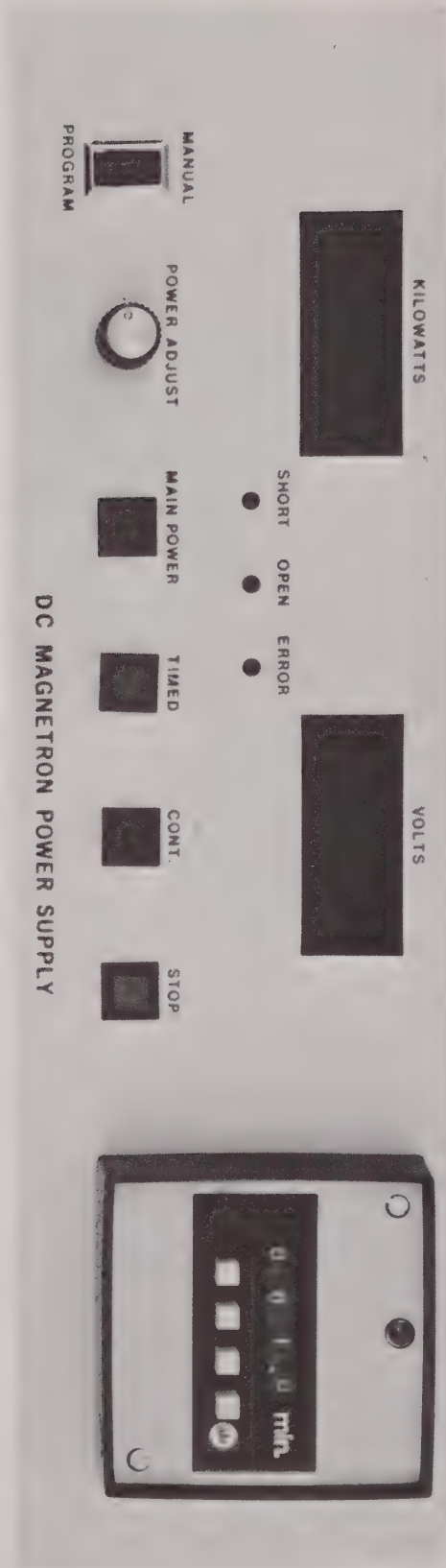
Feedback loop recovery is approximately 1 sec. at a program level of 10 kW.



Non-Programmable 5 kW DC Magnetron Power Supply



Programmable 5 kW DC Magnetron Power Supply



5 and 10 kW DC Magnetron Power Supply Controller

4400 SPUTTERING SYSTEM MODULE

Sputtering Module & Control Unit

The Model 4400 Production Sputtering Modules consists of:

1. RF impedance matching network
2. Control panel
3. Top plate with target and substrate support assemblies
4. Hoist bracket with argon inlet, cooling water inlet and outlet, and a plug for the control cable.

RF Impedance Matching Network

The impedance matching network is located in the top of the unit. This network matches impedance of the cathode/discharge/anode (substrate table) system to the standard 50-ohm impedance of the coaxial line which brings RF power from the power generator. Without a proper match, the RF power generator cannot deliver power for the sputtering process. Instead, reflected waves travel back in the coaxial cable causing standing waves and heating of the cable and certain power generator components. Under severe circumstances, this could destroy the cable or power generator.

The matching network is designed to allow independent adjustment in matching the real and imaginary parts of the impedance. A proper matching can be achieved even with wide variations in deposition parameters such as target size, target-to-substrate distance, argon pressure, etc.

Impedance matching is controlled by LOAD and TUNE controls on the front panel.

Control Panel

These controls and indicators are located on the control panel of the Sputtering Module.

MODE SWITCH—Allows selection of the following operating modes:

Sputter Deposit—In this mode, all RF power is applied to the target; i.e., only the target is bombarded by ions and sputtered. The substrate table is grounded. Self-bias is read on the TARGET BIAS meter.

Bias Sputter—RF power is applied to the target, but a small amount of RF power is also applied to the substrate table. Consequently, substrates also are bombarded by ions, but to a much smaller degree than the target. In many cases this technique yields higher quality deposits than RF sputtering with grounded substrates. Bias is read on the SUBSTRATE BIAS meter.

Sputter Etch—All RF power is applied to the substrate table and material is removed (etched away) from the substrates by ion bombardment. Self-bias is read on the SUBSTRATE BIAS meter.

DC Bias (optional)—This mode is essentially the same as Sputter Deposit. However, instead of grounding the substrate table, a DC bias can be applied to it from an external DC power source.

TARGET SELECTOR Switch—Connects output of the matching circuit to any of the three targets and substrate table. At TARGET 1, power is applied to the left target, as viewed from the front of the unit; TARGET 2 is the rear target; TARGET 3 is at the right, when viewed from the front of the unit. At the ETCH position, RF power is applied to the substrate table. The TARGET 1 and 3 position is used only with the RF power splitting option.

BIAS ADJUST Control—Active only in the BIAS SPUTTER operating mode. This control adjusts the percentage of RF power applied to the substrate table. Varying amount of power results in varying negative self-bias on the table. This bias is measured by the SUBSTRATE BIAS meter. This meter measures energy with which ions from the discharge strike the substrate table.

LOAD Control—Adjusts coupling between primary and secondary circuits of the matching network.

TUNE Control—Adjusts parallel capacitance in the target circuit of the matching network.

RF POWER ON/OFF Switch—Actuates, through a special logic circuit, a high-voltage relay in the RF power generator. The on/off function is interlocked by a pressure interlock switch so that RF voltage cannot be applied to targets while they are exposed to atmospheric pressure. Applying high RF voltage to exposed targets can result in arcing and breakdown around target edges. Target assembly is designed for operation at low pressures where breakdown distance is much longer than at atmospheric pressure.

RF POWER ADJUST Control—Governs power output from the RF power generator. This quantity is measured by a directional coupler in the generator and measured value is displayed on the FORWARD POWER meter.

REFLECTED POWER METER—Measures amount of RF power flowing back from sputtering unit to power supply due to improper adjustment of the matching network. This reflected wave combines in the cable with the forward wave to form standing waves, which in turn, cause heating of the cable. With proper adjustment of LOAD and TUNE controls, reading on the REFLECTED POWER meter should not exceed 10 to 15 W for any amount on the FORWARD POWER meter. Residual reflected power is due to transitions on the cable (such as connectors, etc.) and cannot be eliminated practically.

SHUTTER POSITION Switch—This two-position switch actuates a motor which opens and closes a rotatable disk shutter interposed between the substrates and target. In the OPEN position, the shutter opening permits deposition. In the CLOSED position, it permits etching. The shutter may be adjusted so the shutter-to-table spacing permits etching or bias deposit only through the shutter opening. The amber lamp above the switch is on during shutter rotation.

TABLE SPACING METER—Indicates the distance between the cathode and anode. (Target to substrate spacing).

METERING VALVE (Argon Gas)—A stainless steel needle metering valve equipped with a precision micrometer head for accurate and repeatable settings. Turning the head clockwise closes the valve. Proper setting is empirically determined and depends on desired argon pressure as well as system pumping capability.

ARGON SHUT-OFF SOLENOID VALVE—Connected in series with argon metering valve. In operation, the argon metering valve is adjusted to give desired working pressure of argon. The shut-off solenoid valve closes and opens argon flow without changing the metering valve setting. This solenoid valve is actuated by the GAS control on the automatic pumpdown controller.

CAUTION

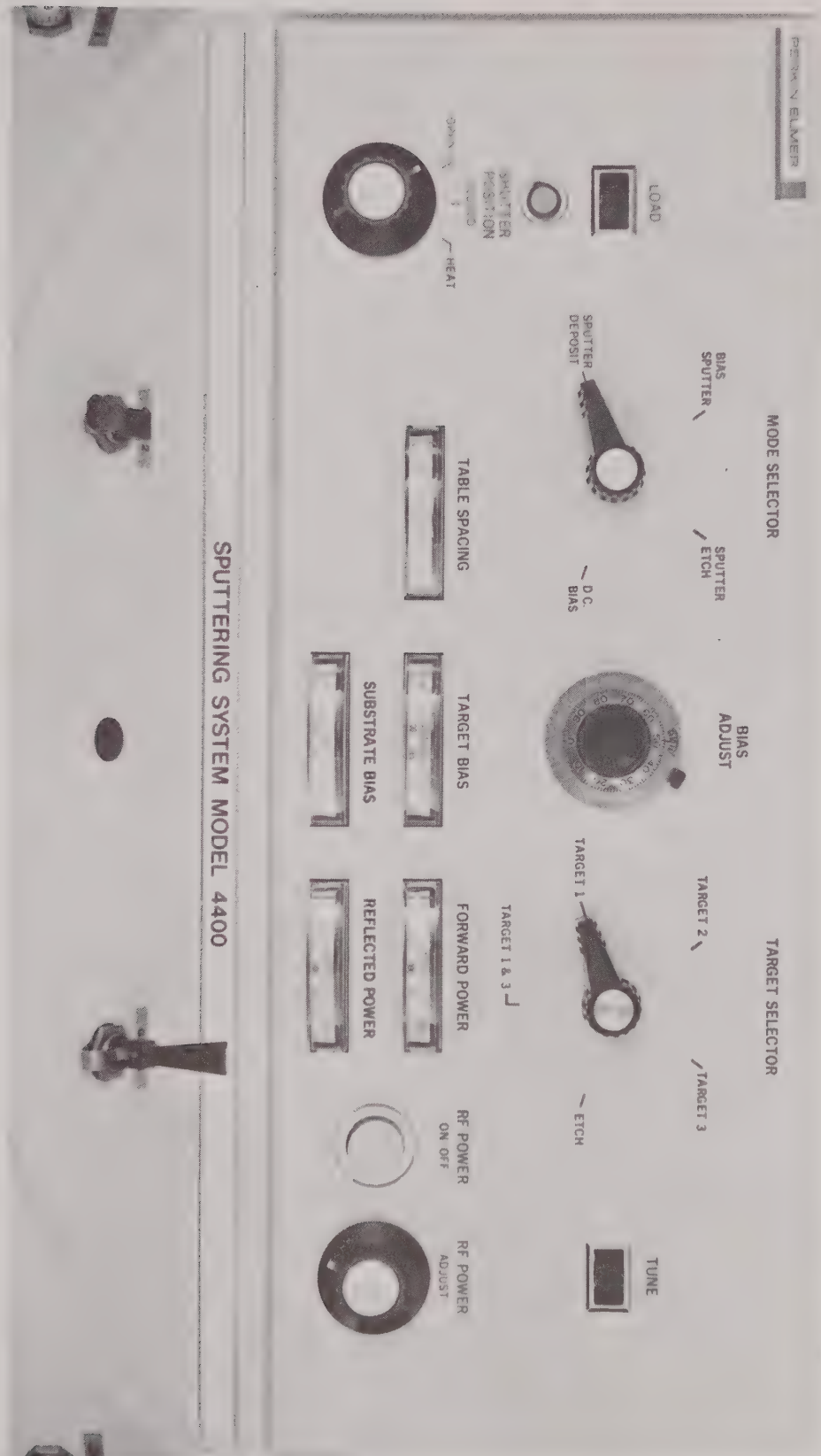
Never try to close the metering valve completely. This would damage its needle and seat.

At the back of the unit, near the hoist adapter, is an RF connector (N-type) to which the RF power cable from the generator is connected.

On both sides of the hoist adapter, located on the wrap-around cover panels, are four screw heads for the adjustable three-turn panel locking pawls.

WARNING

Never operate the unit without cover panels securely in place. High RF voltage develops in the circuitry during operation. Do not defeat the interlocks.



SPUTTERING SYSTEM MODEL 4400

4400 Sputtering System Control Panel

4410 SPUTTERING SYSTEM MODULE

Sputtering Module & Control Unit

The Model 4410 Production Sputtering Modules consists of:

1. RF impedance matching network
2. Control panel
3. Top plate with target and substrate support assemblies
4. Hoist bracket, argon inlet, cooling water inlet and outlet, and a plug for the control cable.

RF Impedance Matching Network

The impedance matching network is located in the top of the unit. This network matches impedance of the cathode/discharge/anode (substrate table) system to the standard 50-ohm impedance of the coaxial line which brings RF power from the power generator. Without a proper match, the RF power generator cannot deliver maximum power for the sputtering process. Instead, reflected waves travel back in the coaxial cable causing standing waves and heating of the cable and certain power generator components. Under severe circumstances, this could destroy the cable or power generator.

This matching network is designed to allow independent adjustment in matching the real and imaginary parts of the impedance. A proper matching can be achieved even with wide variations in deposition parameters such as target size, target-to-substrate distance, argon pressure, etc.

Impedance matching is controlled by LOAD and TUNE controls on the front panel.

Control Panel

These controls and indicators are located on the control panel of the Sputtering Module.

MODE SWITCH—Allows selection of the following operating modes:

Sputter Deposit—In this mode all RF power is applied to the target; i.e., only the target is bombarded by ions and sputtered. The substrate table is grounded. Self-bias is read on the TARGET BIAS meter.

Bias Sputter—RF power is applied to the target, but a small amount of RF power also is applied to the substrate table. Consequently, substrates also are bombarded by ions, but to a much smaller degree than the target. In many cases this technique yields higher quality deposits than RF sputtering with grounded substrates. Bias is read on the SUBSTRATE BIAS meter.

Sputter Etch—All RF power is applied to the substrate table and material is removed (etched away) from the substrates by ion bombardment. Self-bias is read on the TARGET BIAS meter.

DC—The mode is essentially the same as Sputter Deposit. However, instead of RF power, DC power can be applied to the targets.

TARGET SELECTOR Switch—Connects output of the matching circuit to any of the three targets and substrate table. At TARGET 1, power is applied to the left target, as viewed from the front of the unit; TARGET 2 is the rear target; TARGET 3 is at the right, when viewed from the front of the unit. At the ETCH position, RF power is applied to the substrate table.

BIAS ADJUST Control—Active only in the BIAS SPUTTER operating mode. This control adjusts percentage of RF power applied to the substrate table. Varying amount of power results in varying negative self-bias on the table. This bias is measured by the SUBSTRATE BIAS meter. This meter measures the energy with which ions from the discharge strike the substrate table.

LOAD Control—Adjusts coupling between primary and secondary circuits of the matching network.

TUNE Control—Adjusts parallel capacitance in the target circuit of the matching network.

RF POWER ON/OFF Switch—Actuates, through a special logic circuit, a high-voltage relay in the RF power generator.

The on/off function is interlocked by a pressure interlock switch so that RF voltage cannot be applied to targets while they are exposed to atmospheric pressure. Applying high RF voltage to exposed targets can result in arcing and breakdown around target edges. Target assembly is designed for operation at low pressures where breakdown distance is much longer than at atmospheric pressure.

RF POWER ADJUST Control—Governs power output from the RF power generator. This quantity is measured by a directional coupler in the generator and measured value is displayed on the FORWARD POWER meter.

REFLECTED POWER METER—Measures amount of RF power flowing back from sputtering unit to power supply due to improper adjustment of the matching network. This reflected wave combines in the cable with the forward wave to form standing waves, which in turn, cause heating of the cable. With proper adjustment of LOAD and TUNE controls, reading on the REFLECTED POWER meter should not exceed 10 to 15 W for any amount on the FORWARD POWER meter. Residual reflected power is due to transitions on the cable (such as connectors, etc.) and cannot be eliminated practically.

SHUTTER POSITION Switch—This two-position switch actuates a motor which opens and closes a rotatable disk shutter interposed between the subsrates and target. In the OPEN position, the shutter opening permits deposition. In the CLOSED position, it permits etching. The shutter may be adjusted so the shutter-to-table spacing permits etching or bias deposit only through the shutter opening. Shutter rotation is indicated by the two lamps above the shutter position switch. When the shutters are rotating the lamps are on. Red denotes the vane shutter and amber denotes the full circle shutter.

TABLE SPACING METER—Indicates the distance between the cathode and anode (target to substrate spacing).

LIGHT Switch—Manual control of filament igniter to allow observation in the chamber.

When the switch is depressed the sputtering chamber is illuminated by the filament.

SEQUENCE Switch—This two-position switch selects the programmed or non-programmed operation of the sputtering module. In the AUTO position, the module is in the programmed mode for microprocessor operation. In the MANUAL position the module is in the non-programmed mode for manual operation.

METER VALVE (Argon Gas)—A stainless steel needle metering valve equipped with a precision micrometer head for accurate and repeatable settings. Turning the head clockwise closes the valve. Proper setting is empirically determined and depends on desired argon pressure as well as system pumping capability.

ARGON SHUT-OFF SOLENOID VALVE—Connected in series with argon metering valve. In operation, the argon metering valve is adjusted to give desired working pressure of argon. The shut-off solenoid valve closes and opens argon flow without changing the metering valve setting. This solenoid valve is actuated by the GAS control on the automatic pumpdown controller.

CAUTION

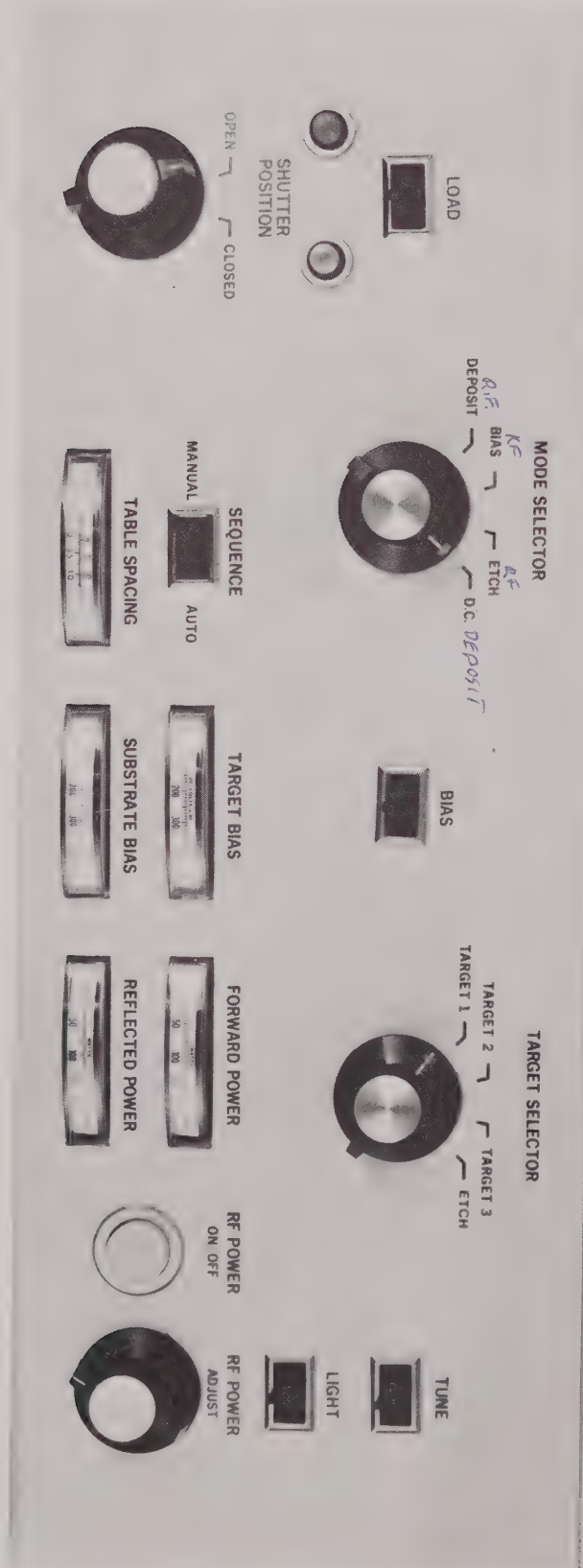
Never try to close the metering valve completely. This would damage its needle and seat.

At the back of the unit, near the hoist adapter, is an RF connector (N-type) to which the RF power cable from the generator is connected.

On both sides of the hoist adapter, located on the wrap-around cover panels, are four screw heads for the adjustable three-turn panel locking pawls.

WARNING

Never operate the unit without cover panels securely in place. High RF voltage develops in the circuitry during operation. Do not defeat the interlocks.



4410 Sputtering System Control Panel

SERVO CONTROL

Servo-Match Control

Servo-Match Automatic Tuning

Power from the RF generator is impedance matched for the sputtering plasma by means of an impedance matching network built into the sputtering head assembly. This network adjusts the real component of the impedance with an air core transformer in which the primary-to-secondary coupling is varied by moving the primary coil (consisting of two turns of silver-plated copper tubing) in or out of a coaxial relationship to the secondary coil (six turns of silver plated copper tubing). This air core transformer, referred to as the load link, is water-cooled and provides DC isolation between the matching network and the generator. The imaginary component of the impedance is adjusted by the variable tune capacitor. The Servo-Match instrument, which is standard on RF equipped Production Sputtering Systems, automatically maintains proper tuning despite target variation, pressure changes, or RF power changes. The link coil position is set by means of a front panel potentiometer and this instrument servo-adjusts the tune capacitor to maintain tuning.

All operator controls are located on the front panel and all electrical connections are made at the rear panel. A single P.C. board contains the entire electronic circuitry. All power logic and control signals are obtained through the control cable. The sensor box measures the phase relationship in the RF cable.

Modes of Operation

MANUAL

In the manual mode of operation, sputterhead matching impedance can be changed by means of TUNE and LOAD switches located on the sputterhead or meter control chassis.

AUTOMATIC

In the automatic mode of operation, the sputterhead network will match RF generator output automatically.

During the automatic mode, the operator can adjust the tuning capability of this unit. The circuit can be tuned for the minimum reflected power by inserting a small screwdriver into the appropriate potentiometer hole and slowly turning right or left. This is monitored on the sputtering modules' "Reflected Power" meter.



Servo-control (Servo-Match Auto-Tune Control)

POWER STABILIZER

The Power Stabilizer provides regulation of the RF power level delivered to a sputtering chamber. Specifically, constant power will be maintained for sputtering and etching processes despite considerable variations in AC line voltage, gas pressure, work characteristics, and temperature. This device, when used with automatic RF tuning, ensures steady load power regardless of tuning variations in either the associated RF generator or in the sputtering head. All operator controls and indicators are located on the front panel; all electrical connections are made at the rear panel. A printed circuit board contains the major electronic circuits used in the unit. Single-phase, 115 VAC power is converted to DC voltages of +15 and -15V for operating the solid-state internal circuits.

Modes of Operation

The two basic modes of operation are stabilization ON and OFF. A description of each of these modes follows:

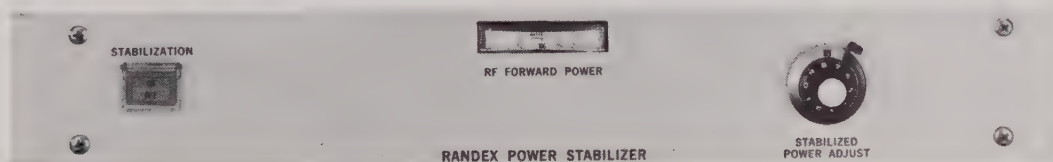
Stabilization On

In this mode of operation, the power level is regulated and controlled by a potentiometer on the front panel. This mode is used for process determination.

Stabilization Off

In this mode of operation, the power level is not regulated, but is adjustable by the RF POWER ADJUST potentiometer located on the sputtering head. This mode is used for initial adjustments and experimental determinations.

All operating power for the Power Stabilizer is derived from the RF generator to which it is cabled.



Power Stabilizer (RF)

TABLE ROTATION SPEED CONTROL

A standard feature on the 4400 series sputtering system is the 1-10 rpm variable speed substrate table rotation. The speed is controlled by the knob on the "Table Rotation Speed Control" panel. Included on this panel is a revolution counter with a manual reset button.



Table Rotation Speed Control

VARIABLE HORIZONTAL POWER SPLITTING

General

With this option, RF power may be applied to two cathodes simultaneously. Power splitting is activated by setting the TARGET SELECTOR switch to the position labeled 1 + 3. A control dial, located in the top section, differentially adjusts two capacitors to achieve the percentage of RF power split desired. Power will be applied to both target 1 and target 3 to permit sputtering from each target at any ratio between 5% and 95%. Independent metering of the self-bias levels on the two targets is provided on the top section panel. If different materials are used for the two targets, an alloy of the materials is formed when the substrate table is rotated continuously. If identical targets are used in the two positions, the sputtering rate is doubled for a fixed power density on each target. The total applied power cannot exceed the 2kW capacity of the matching network. This technique can be used to increase the sputtering rate for targets, such as some types of glass, with high internal stresses that will shatter if high RF power is applied.



Variable Horizontal Split Power Control

DIGITAL CLOCK TIMER

The Digital Clock Timer (D.C.T.) option is available for any RF feature on the 4400 series systems.

The Digital Clock Timer provides an accurate and reliable means of timing sputtering operations. At the end of the designated period, the timer stops the operation automatically, without requiring additional operator attention. Thus, run accuracy is assured by eliminating hit and miss timing, wasted runs, and lost time.

The Digital Clock Timer operates in two modes. In the automatic mode, it starts automatically when the RF power on/off switch on the Sputtering Module is activated. In the manual mode, it is started manually by depressing its own front panel switch. It is possible to switch modes at any point in the process. It is also possible to change the time period at any point.

In either mode, when the preset time has run out, the timer automatically turns off the RF power to the Sputtering Module. Then, the timer automatically resets itself to repeat the previous timing shown on the digital readout, unless the operator changes it.

NOTE

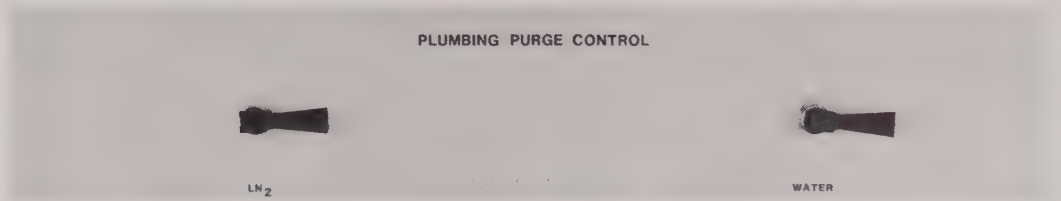
A dual DCT timer panel is shown, however single DCT panels are also available.



Dual Digital Clock Timer

PLUMBING PURGE CONTROL

Another standard item found on all 4400 series systems is the Plumbing Purge Control. This feature allows a technician to blow out all the water lines and LN₂ Trap (Meissner) independently. Once the cooling water and LN₂ have been turned off, the Purge control can be used. By turning either the water or LN₂ purge on, dry nitrogen gas is blown through the lines. This becomes a valuable tool when there is reason to change a target and/or to open the vacuum chamber.



Plumbing Purge Control

CRYOPUMP REGENERATION CONTROL

GENERAL DESCRIPTION

On 4400 Production Sputtering Systems equipped with a closed-cycle helium cryogenic pump, an instrument is included which is used to automatically regenerate the pump. After operating for some time, cryopumps must be regenerated to remove the gas molecules that have been adsorbed on their interior surfaces. The required frequency of regeneration depends on how often the cryopump is used and on the types of gas molecules that are pumped in the vacuum system.

Starting the Regeneration Cycle

Regeneration of the cryopump is initiated by pressing the CYCLE START button on the left side of the control unit's front panel.

Because the process is automatically controlled, the cryopump may be regenerated during an off-shift period. For example, after the last deposition run of the day, the regeneration cycle can be started. The cycle is then automatically completed and the pump and system are fully functional at the beginning of the next shift. The regeneration cycle lasts 3-1/2 hours and consists of the following steps:

1. The high vacuum valve is closed and the compressor is turned off.
2. A solenoid valve is opened to flood the cryopump with dry gas. Nitrogen or argon gas is recommended. The gas warms the pump and flushes desorbed gases out of the pump through a pressure relief valve.
3. After 60 minutes, the gas solenoid closes and an air-driven roughing valve opens, connecting the cryopump to the mechanical pump roughing manifold.
4. The cryopump is roughed for 30 minutes which reduces the pressure to 20 or 25 mTorr (microns) and assures that water vapor has been removed from the pump.
5. After roughing for 30 minutes, the roughing valve is closed and the compressor restarted.
6. After two hours, the cryopump is completely chilled and control is returned to the Automatic Pumpdown Control. If chamber pressure is lower than trip pressure, the high vacuum valve opens.

If chamber pressure has leaked up beyond the crossover pressure, the control will prevent the high vacuum valve from opening. With a cryopumped system, the crossover point from roughing to high vacuum may be set as high as 500 mTorr (microns). It would indicate a major leak problem if the chamber pressure were to rise this high in only 3 hours.



Cryopump Regeneration Control

A convenient feature of the 4400 Production Sputtering System is the power distribution box located inside the left rear corner of the system frame. The external power source is connected to the system at a set of terminal strip contacts and the power distribution box is prewired to provide the correct power to instruments, pumps, valves, controls, power supplies, etc.

17-1

SAMPLE OPERATION SEQUENCE

The following procedure will take you step-by-step through an operational run sequence of a 4400 series system. This provides for a Sputter Etch, a RF Target Deposition and a DC Target Deposition.

Naturally, the best starting point is with a system already set up and operating, as if it were waiting for someone to start the next run. Therefore, the cooling water is on, LN₂ is on, RF and DC power supplies are on, the etch and deposition timers are set, the load lock door is open and the pallet is ready for loading.

1. Load Pallet
2. Closed Load Lock Door (press both Rocker Switches down and hold until roughing valve opens)
3. Wait until the automatic load sequence has completed and the "Loaded" light is on (located on the Load Lock Control Panel). Then monitor the DGC or WRG for chamber recovery to your required base pressure and pumping time.
4. "Mode Selector" switch to "Sputter Etch" position.
5. "Target Selector" switch to "Etch".
6. "Shutter Position" switch to "Closed".
7. Turn gas on (press "Start" and "Gas" buttons on Auto Pumpdown Control simultaneously).

NOTE

Gas "on" mode also starts table rotation.

8. Allow pressure to stabilize (monitor appropriate SW position on DGC or WRG). If gas pressure needs to be adjusted or changed, use the Micrometering valve (located on the sputtering module front panel).
9. Turn RF Power on (press RF Power ON/OFF switch). The filament igniters will light in the chamber (it will appear as if a light had turned on in the chamber).
10. Slowly increase the RF power by turning the "RF Power Adjust" knob cw. As the RF Power is increased, both the "Forward Power" and the "Reflected Power" meters will indicate an increase. Once RF power has lit a plasma, the following will take place:
 - a. The Servo-Match will automatically tune for minimum reflected power.
 - b. The "Substrate Bias" meter will indicate the substrate voltage level.
 - c. The Filament igniters will turn off (this is controlled by the Bias Voltage—Voltage sensor circuit turns igniters off).
11. Increase RF power to required Etch power for the run.
12. Start Etch timer (the timer will turn the RF power off at the end of the timed cycle).
13. After the Etch cycle has timed out, turn "RF Power Adjust" knob back to zero (fully ccw).
14. "Mode Selector" switch to "Sputter Deposit".
15. "Target Selector" switch to "Target 2" (in this example #2 is the RF Cathode).
16. Turn RF power on (press "RF Power On/Off" switch). The Filament igniters will light in the chamber.
17. Slowly increase the RF power by turning the "RF Power Adjust" knob cw. As the RF power is increased both the "Forward Power" and the "Reflected Power" meters will indicate an increase. Once the RF power has lit a plasma the following will take place:
 - a. The Servo-Match will automatically tune for minimum reflected power.
 - b. The "Target Bias" meter will indicate the target voltage level.
 - c. The filament igniters will turn off.
18. Increase RF power to required deposition power for the run.
19. "Shutter Position" switch to "Open".

NOTE

The Amber light over the "Shutter Position" switch will turn on. When the light is on, it indicates the shutter is rotating. When the light goes out the shutter has reached the required position.

20. As soon as the shutter rotation light goes out, start the deposition timer (the timer will turn the RF power off at the end of the timed cycle).
21. After the deposition timer has timed out, turn "RF Power Adjust" knob back to zero (fully ccw).
22. "Shutter Position" switch to "Closed".
23. "Target Selector" switch to "Target 1" (in this example #1 is the DC Magnetron Cathode).
24. Press the "Continuous" button, on the DC Magnetron Control Panel and slowly turn "Power Adjust" knob up (cw) to required power level. The power is read on the meters located on the same control panel.
25. "Shutter Position" switch to "Open".
26. As soon as the shutter has opened, (as explained in #19) press the "Time" button (the timer will turn the RF power off at the end of the timed cycle).
27. After the deposition timer has timed out, turn the "Power Adjust" knob back to zero (fully ccw).
28. "Shutter Position" switch to "Closed".
29. On Auto Pumpdown Controller, press "Start" and "Pump" buttons simultaneously. This turns the gas off.
30. Monitor base pressure recovery on the DGC or WRG, if process requires this. (If DGC used—filament must be turned back on.)
31. On Load Lock Control panel, press "Start" and "Unload" buttons simultaneously. The pallet will now be transferred back to the Load Lock chamber automatically and the Lock vented.
32. When the Lock at "ATM" light comes on (located on the water flow switch panel), push both Load Lock Door rocker switches to the up mode and hold until the door is all the way open. The elevator will then raise the pallet automatically.
33. Unload pallet and reload next run.

APPENDIX B

MICROPROCESSOR PROCESS CONTROLLER

INTRODUCTION

The Microprocessor Process Control (MPC), as shown in Figure B-1, was designed to implement the concept of a "hands-off" processing system to control production line sputtering. The design does not require operator intervention other than the loading of materials to be processed and closing the Load Lock door. The remaining operations will be under the control of the MPC system which may be pre-programmed to perform the cycles of operation required by the sputtering process.

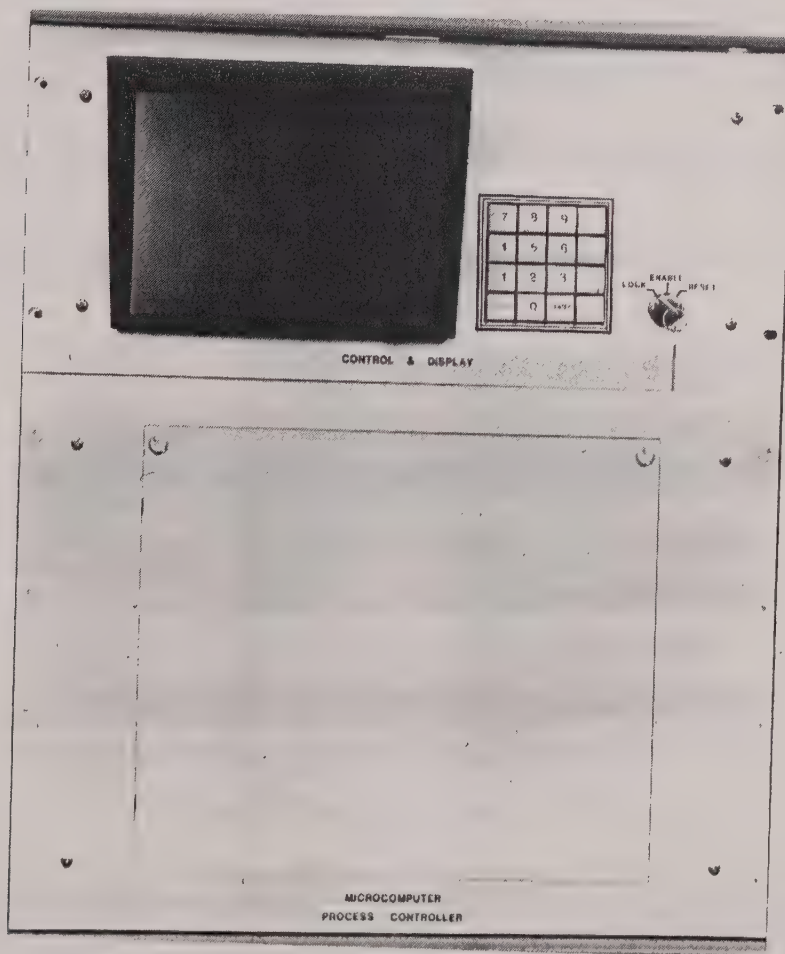


Figure B-1 MICROPROCESSOR PROCESS CONTROLLER

The following describe the various modes of operation of the MPC:

1. Production Sputtering—In this mode, the process is initiated by the closing of the Load Lock door. When in this mode, the operator has minimal control over the process.
2. Set-up Programming—In this mode, the line supervisor can unlock the MPC with his key and perform the following:
 - a. Set the MPC to a different process.
 - b. Change process parameters.
 - c. Operate the system in the Manual Mode.
3. Process Development/Maintenance—When the MPC is unlocked, the manual mode and status display functions can be used to develop a new process or perform service on the sputtering process.

The Operator interfaces with the MPC through the Display Unit (DU), which consists of a CRT display, a keyboard, and a Key Lock. All operator commands are entered through the keyboard and displayed on the CRT.

CRT DISPLAY SCREEN

The data typed on the keyboard is displayed on the screen as it is entered. This allows the operator to observe and correct entry errors.

A cursor is always displayed on the screen when the power is on. The cursor is an underscore character (-), to indicate where the next data will be displayed on the screen.

The system displays messages on this screen to inform the operator of normal and abnormal conditions.

KEYBOARD

There are 16 keys on the keyboard, 13 of which are functional. Before using the system, the operator should be thoroughly acquainted with the meaning and use of each key.

Digit Keys (0–9)

These keys enter numeric information into the system. The digit is also displayed on the screen at the cursor.

Enter Key

This key sends commands and statements entered on the keyboard to the system for execution or processing.

Delete Key

This key is used whenever an incorrect command or statement is typed. It must be used before the ENTER key is pressed. When pressed, the system deletes information previously typed and prompts for the information to be re-entered.

Decimal Point Key (.)

This key enters a decimal point into the system, and recalls the MPC to display the main menu command code display. The decimal point is displayed on the screen at the cursor.

The Perkin-Elmer microprocessor controller option permits automated control of machine functions and process parameters, including load lock operation, pumpdown venting, and all process sequences. Up to six, 16-step operation process sequences can be stored in the system's memory to facilitate process changes.

An interactive CRT facilitates programming. Unconditional looping is available for distributed system applications.

Table B-1 shows the MPC Main Menu Command Code Display. By pressing O, ENTER, the operator will recall the MPC to display the main menu command code display. Each function in turn may have one or more menu displays and further sub-functions. The operator selects a sub-function from the back menu by entering command code number followed by ENTER. As the numbers are entered, they are displayed on the CRT. If an invalid number is entered, or if more than 4 digits are entered, the input is erased.

Edit Process Mode

The operator has the capability at any time during the entry process of recalling all entered steps for review, and of editing the sequence at any time to correct any parameter or step to achieve the desired results. It is possible to create repeated sequences (for instance HEAT-DEPOSIT sequence repeated three times) without the need of individually specifying each component each time.

In the EDIT process mode, a selection is made by entering the command: 1, ENTER 2, ENTER or 3, ENTER, depending on the desired action, when the main menu is displayed on the CRT.

The system will prompt by displaying:

1. EDITOR: Note the following process programs that are available:

0. End
1. Heat
2. Standby
3. Etch
4. Preclean
5. Deposit
6. Repeat

P T I
S T
R P
S
P
P

First select process steps (1 through 5)

2. After selecting any combination from the six process programs, the list of process steps is displayed on the screen (up to 15 process programs can be selected). For example:

STEP #	ACTION	RF/DC	TARG.	POWER	DURATION	RAMP	PRESS	BIAS	PROCESS #
1	1—Heat	—	—	—	—	—	—	—	—
2	2—Standby	—	—	—	—	—	—	—	—
3	5—Deposit	—	—	—	—	—	—	—	—
4	2—Standby	—	—	—	—	—	—	—	—
5	6—Loop	—	—	—	—	—	—	—	—

When given this list of entries the operator may now insert, modify, or delete steps in the following manner:

1. By entering nn ENTER, the modify function can be recalled starting at step nn. The display is redrawn showing only the desired and prompted step:

STEP # ACTION RF/DC TARGET POWER TIME

3 5—Deposit

3—(The curser is positioned at the first modifiable parameter.) The user may type in either of the following new parameters:

- a. The ENTER alone to accept the displayed parameter and advance to the next prompt.
- b. 0 ENTER to delete the whole step.
- c. . (period) ENTER, to escape from the modify function.

Upon entering the desired command, the next step is displayed and the cursor is moved the appropriate parameter.

2. The prompt nn ENTER requests the insert function starting before step nn. The display is redrawn showing the steps preceding the entry point.

For example:

STEP #	ACTION	RF/DC	TARG.	POWER	TIME
1	2—Standby	—	—	—	—
2	1—Heat	—	—	—	—
3	(The cursor is positioned at the first entry point).				

As in paragraph 1 above, the user may enter a new parameter or (.) ENTER to escape from inserting. The prompt 0 ENTER puts an END to step at 3, and automatically escapes. The ENTER key is ignored in the insert function if pressed alone.

3. Following the escape (. ENTER), the program returns and displays the list of steps on the CRT. An escape (. ENTER) or end (0 ENTER) will return the system to the main menu. Also, an escape (. ENTER) from any other parameter on a cue will rubout that line and reprompt for it.

TABLE B-1

MAIN MENU COMMAND CODE DISPLAY

1. Enter Process
2. Delete Process
3. Modify Process
4. List Process
5. Auto Operate
6. Manual Operate
7. Display Status

Auto Operate Mode

The AUTO OPERATE mode is called from the main menu command code display option 2. By pressing 2 ENTER, the selection becomes valid and the program will proceed to execute the process if that process exists and has an END step compiled.

After scanning the system, the MPC will inform the operator of all abnormalities before proceeding with a process. If the elevator is down, the carriage is out, and the LOAD LOCK door is locked, the operator will be asked to correct the deficiencies. These deficiencies can be corrected by switching into the Manual Operator Mode (.6 ENTER).

After satisfying all the preconditions, the operator returns the MPC back to Auto Operate mode and the program will prompt the operator to close the Load Lock door before initiating pumpdown.

During STANDBY and HEAT processes the pallet need not be placed in the chamber. The STANDBY process requires only that the Load Lock be maintained at trip, which will be accomplished during automatic pumpdown routine. Also, when heating process takes place in the Load Lock, the pallet requires no movement. However, in the DEPOSIT, ETCH, and PRECLEAN process, the pallet is moved to the chamber once reaching the thermocouple gauge trip point.

It is possible to go directly to any mode without intermediate preparation. If an automatic sequence has been created that requires movement from STANDBY or HEAT to DEPOSIT and then back to HEAT or STANDBY, loading and unloading of the pallet is automatic and does not require operator intervention.

When the DEPOSIT, PRECLEAN or ETCH mode is selected, the program will automatically select the preprogrammed target, move the shutter, and monitor the DGC for the programmed set point to begin the sequence. If, however, no setpoint is selected, the thermocouple gauge trip point can be used by entering 00. At the DGC gauge trip, the program will begin to ramp the selected sputter power source toward its setpoint.

When an indication of activity is received, the RF igniter will be turned off by the MPC. When the setpoint is reached, an internal timer will be activated and the duration display will be placed on the CRT. At the endpoint of the duration, the power source will be turned off and the next step will be interpreted.

If the next step is an END, the pallet will be automatically unloaded, and when the Load Lock is secure, the lock vent will open. When the Load Lock is at atmosphere, the program will allow an additional 30 seconds and then close the vent. The operator will be signaled on the CRT to remove the pallet. This operation will reset the program, and the operator will be prompted to place another substrate pallet on the Load Lock and close the door.

This action will recycle the selected procedure on an endless basis. If it is desired to escape from the process, unlocking the keyboard and pressing 0 ENTER will return the operator to the main menu command mode display.

Manual Operate Mode

When the user enters into MANUAL OPERATE MODE (6 ENTER), the front page of the available commands will be displayed on the CRT screen. As shown in Table B-2, there are a total of three pages of commands. Pressing the ENTER key will display the next page of commands. If ENTER is pressed while the CRT is displaying page 4, the MPC will wrap around and return to the first page.

TABLE B-2

MANUAL OPERATE MODE

MANUAL OPERATE MODE PAGE 1

00 RECALL MAIN MENU	12 HI-VAC PUMP OFF
01 CHAMBER VENT OPEN	13 HI-VAC VALVE OPEN
02 CHAMBER VENT CLOSE	14 HI-VAC VALVE CLOSE
03 LOCK VENT OPEN	15 THROTTLE VALVE OPEN
04 LOCK VENT CLOSE	16 THROTTLE VALVE CLOSE
05 CHAMBER ROUGH OPEN	17 LOCK HI-VAC VALVE OPEN
06 CHAMBER ROUGH CLOSE	18 LOCK HI-VAC VALVE CLOSE
07 LOCK ROUGH OPEN	19 LOCK VALVE OPEN
08 LOCK ROUGH CLOSE	20 LOCK VALVE CLOSE
09 MECHANICAL PUMP ON	21 CARRIAGE INSERT
10 MECHANICAL PUMP OFF	22 CARRIAGE WITHDRAW
11 HI-VAC PUMP ON	23 LOCK ELEVATOR UP

MANUAL OPERATE MODE PAGE 2

24 LOCK ELEVATOR DOWN	36 SHUTTER 2 CLOSE
25 TABLE UP	37 TARGET 1
26 TABLE DOWN	38 TARGET 2
27 TABLE ROTATE ON	39 TARGET 3
28 TABLE ROTATE OFF	40 TARGET 4
29 GAS ON	41 LN ₂ VALVE OPEN
30 GAS OFF	42 LN ₂ VALVE CLOSE
31 SHUTTER TO POS. 1	43 HORN ON
32 SHUTTER TO POS. 2	44 HORN OFF
33 SHUTTER TO POS. 3	45 CHAMBER HEATERS OFF
34 SHUTTER TO POS. 4	46 CHAMBER HEATER 1 ON
35 SHUTTER 2 OPEN	47 CHAMBER HEATER 2 ON

MANUAL OPERATE MODE PAGE 3

48 LOCK HEATERS OFF	60 RF ON
49 LOCK HEATER 1 ON	61 RF OFF
50 LOCK HEATER 2 ON	62 BIAS MOTOR FORWARD
51 BIAS MODE	63 BIAS MOTOR REVERSE
52 ETCH MODE	64 BIAS MOTOR STOP
53 DEPOSIT MODE	65 AUTO MODE ON
54 IGNITION ON	66 AUTO MODE OFF
55 IGNITION OFF	67 DGC #1 FIL. OFF
56 DC ENABLE ON	68 DGC #1 FIL. ON
57 DC ENABLE OFF	69 DGC #2 FIL. ON
58 MAGNETRON ON	70 DGC #2 FIL. OFF
59 MAGNETRON OFF	

In the manual mode of operation, it is possible to change the state of any function in the Model 4410 System over which the MPC has control. In some cases the operation of certain valves in a certain sequence may have an undesirable effect, such as flooding the cryopump. In order to prevent the operator from inadvertently damaging the integrity of the system, a series of manual mode interlocks (MMI) has been established.

In order to activate a certain manual mode function, the operator enters the number of the function followed by ENTER. At this point any of the following may occur:

1. The command will be executed if no interlock conflicts exist. In this case the system will respond with the message 'OK'.
2. 'RAISE ELEVATOR'. While the MPC is working on such a function, the message 'WORKING' will be displayed. Some of these functions provide a signal to tell the MPC that the command was successfully executed. If such a signal is available, the message 'OK' will be displayed when it is received. If the signal is not received after a certain amount of time known as the timeout interval, the screen will be cleared and an error message will be displayed. A typical error message would be 'UNABLE TO RAISE ELEVATOR'.
3. If an interlock conflict is detected, the screen is erased and a list of the conditions creating the interlock conflicts is displayed. For example, 14 'HI-VAC VALVE CLOSE' means that the HI-VAC valve is open and must be closed before the command can be executed. If there is no number preceeding the error condition, the interlock is being created by a sensor input to the MPC, over which the operator has no direct control. If the command 'HI-VAC OPEN' is issued, and the chamber is at air, the error message 'CHAMBER TRIP' will be displayed. This condition can be corrected by the command 'CHAMBER ROUGH OPEN'.

The interlocks may be unconditionally over-ridden. When the operator wishes to have some function performed, regardless of any other conditions in the machine, the interlock override procedure must be used. This procedure consists of several steps:

1. Enter the two digit function code. (Normally it is not necessary to enter leading zeros. While in this mode, two digits must be used. For example the function code 5 would be entered as 05 when in the interlock mode.)
2. Enter a decimal point (.).
3. Press ENTER. If any interlocked conditions exist, such as with the non-interlocked mode, they will be displayed with the message 'INTERLOCKED! RE-ENTER COMMAND TO EXECUTE'.
4. Re-enter the command as in steps 1-3. If the same command is entered, it will then be unconditionally executed. If the second command does not exactly match the first, the command will be aborted and the operator will be returned to the current display page. If the second command is the same as the first, the command will be executed as in the standard manual mode as if no interlock conditions existed.

A list of manual operate mode commands, their control bits, and interlock conditions is given in Table B-3.

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TABLE B-3

MANUAL MODE FUNCTIONS

00 RETURN TO MAIN MENU NO RESTRICTIONS	08 LOCK ROUGH CLOSE NO RESTRICTIONS
01 CHAMBER VENT RESTRICTIONS: CHAMBER ROUGH HI-VAC VALVE	09 MECH. PUMP ON NO RESTRICTIONS
02 CHAMBER VENT CLOSE NO RESTRICTIONS	10 MECH. PUMP OFF NO RESTRICTIONS
03 LOCK VENT OPEN RESTRICTIONS: LOCK ROUGH CLOSE LOCK HI-VAC CLOSE	11 HI-VAC ON NO RESTRICTIONS
04 LOCK VENT CLOSE NO RESTRICTIONS	12 HI-VAC OFF NO RESTRICTIONS
05 CHAMBER ROUGH OPEN RESTRICTIONS: PUMP ON VENT CLOSED HI-VAC CLOSED	13 HI-VAC VALVE OPEN RESTRICTIONS: CHAMBER TRIP HI-VAC PUMP ROUGH VALVE
06 CHAMBER ROUGH CLOSE NO RESTRICTIONS	14 HI-VAC VALVE CLOSE NO RESTRICTIONS
07 LOCK ROUGH OPEN RESTRICTIONS: PUMP ON DOOR CLOSED VENT CLOSED HI-VAC CLOSED	15 THROTTLE VALVE OPEN NO RESTRICTIONS
	16 THROTTLE VALVE CLOSE NO RESTRICTIONS
17 LOCK HI-VAC OPEN LOCK DOOR LOCK TRIP LOCK VENT	(MUST BE CLOSED) (MUST BE AT TRIP) (STATUS=1) (MUST BE CLOSED)
18 LOCK HI-VAC CLOSE NO RESTRICTIONS	
19 LOCK VALVE OPEN ELEVATOR LOCK TRIP	(MUST BE UP) (MUST BE AT TRIP) (STATUS=1)
20 LOCK VALVE CLOSE ELEVATOR	(MUST BE UP)

21 INSERT CARRIAGE

RESTRICTIONS:

LOCK VALVE (MUST BE OPEN)
ELEVATOR (STATUS=DOWN)
CARRIAGE (STATUS=OUT)

PROCEDURE:

1. TURN WITHDRAW CARRIAGE OFF
2. WAIT 100ms FOR RELAY
3. TURN INSERT CARRIAGE ON
4. IF STATUS = INSERTED (1) THEN NORMAL EXIT
5. IF TIMEOUT (INTERVAL = 8 SEC.) THEN ERROR EXIT
NORMAL EXIT PRINT 'OK' ON SCREEN
TURN INSERT CARRIAGE OFF
ERROR EXIT TURN INSERT CARRIAGE OFF
DISPLAY ERROR MESSAGE

22 WITHDRAW CARRIAGE

RESTRICTIONS:

LOCK VALVE (MUST BE OPEN)
ELEVATOR STATUS (MUST BE DOWN)
CARRIAGE STATUS (MUST BE IN)

PROCEDURE:

1. TURN INSERT CARRIAGE OFF
2. WAIT 100 ms. FOR RELAY
3. TURN WITHDRAW CARRIAGE ON
4. IF CARRIAGE STATUS = OUT (1) THEN NORMAL EXIT OR
5. IF TIME INTERVAL = 8 SEC. THEN ERROR EXIT
BOTH EXITS TURN WITHDRAW CARRIAGE OFF

23 LOCK ELEVATOR UP

RESTRICTIONS:

CARRIAGE STATUS (MUST BE OUT)

PROCEDURE:

1. SET TO RAISE
2. IF STATUS = UP (1) THEN NORMAL EXIT OR
3. IF TIMEOUT (5 SEC.) THEN ERROR EXIT

24 LOCK ELEVATOR DOWN

RESTRICTIONS

CARRIAGE STATUS (MUST BE OUT)

PROCEDURE:

1. SET TO LOWER
2. IF STATUS = DOWN (1) THEN NORMAL EXIT OR
3. IF TIMEOUT (5 SEC.) THEN ERROR EXIT

25 TABLE UP

SPECIAL DEVICE HANDLER

NO RESTRICTIONS

PROCEDURE:

1. TURN TABLE DOWN OFF
2. WAIT 100 ms.
3. TURN TABLE UP ON
4. DELAY FOR 5 SEC.
5. TURN TABLE UP OFF
6. EXIT

- 26 TABLE DOWN
NO RESTRICTIONS
PROCEDURE:
1. TURN TABLE UP OFF
2. DELAY FOR 100 ms.
3. TURN TABLE DOWN ON
4. DELAY FOR 5 SEC.
5. TURN TABLE DOWN OFF
6. EXIT
SPECIAL DEVICE HANDLER
- 27 TABLE ROTATE ON
RESTRICTIONS:
TABLE
(MUST BE UP)
- 28 TABLE ROTATE OFF
NO RESTRICTIONS
- 29 GAS ON
RESTRICTIONS:
LOCK VALVE
CHAMBER TRIP
(STATUS MUST = CLOSED)
(MUST BE BELOW TRIP POINT)
- 30 GAS OFF
NO RESTRICTIONS
- 31 SHUTTER 1
NO RESTRICTIONS
PROCEDURE:
SHUTTER 2 OFF
SHUTTER 3 OFF
SHUTTER 4 OFF
SHUTTER 1 ON
- 32 SHUTTER 2
NO RESTRICTIONS
PROCEDURE:
SHUTTER 1 OFF
SHUTTER 3 OFF
SHUTTER 4 OFF
SHUTTER 2 ON
- 33 SHUTTER 3
NO RESTRICTIONS
PROCEDURE:
SHUTTER 1 OFF
SHUTTER 2 OFF
SHUTTER 4 OFF
SHUTTER 3 ON
- 34 SHUTTER 4
NO RESTRICTIONS
PROCEDURE:
SHUTTER 1 OFF
SHUTTER 2 OFF
SHUTTER 3 OFF
SHUTTER 4 ON

35 SHUTTER 2 OPEN
NO RESTRICTIONS

36 SHUTTER 2 CLOSE
NO RESTRICTIONS

37 TARGET 1
NO RESTRICTIONS
PROCEDURE:
TARGET 2 OFF
TARGET 3 OFF
TARGET 4 OFF
TARGET 1 ON

38 TARGET 2
NO RESTRICTIONS
PROCEDURE:
TARGET 1 OFF
TARGET 3 OFF
TARGET 4 OFF
TARGET 2 ON

39 TARGET 3
NO RESTRICTIONS
PROCEDURE:
TARGET 1 OFF
TARGET 2 OFF
TARGET 4 OFF
TARGET 3 ON

40 TARGET 4
NO RESTRICTIONS
PROCEDURE:
TARGET 1 OFF
TARGET 2 OFF
TARGET 3 OFF
TARGET 4 ON

41 LN₂ VALVE OPEN
NO RESTRICTIONS

42 LN₂ VALVE CLOSE
NO RESTRICTIONS

43 HORN ON
NO RESTRICTIONS

44 HORN OFF
NO RESTRICTIONS

45 CHAMBER HEAT OFF
NO RESTRICTIONS
PROCEDURE:
HEATER #1 OFF
HEATER #2 OFF

46 HEATER #1 ON
NO RESTRICTIONS

47 HEATER #2 ON
NO RESTRICTIONS

48 LOCK HEAT OFF
NO RESTRICTIONS
PROCEDURE:
HEATER #1 OFF
HEATER #2 OFF

49 LOCK HEATER #1 ON
NO RESTRICTIONS

50 LOCK HEATER #2 ON
NO RESTRICTIONS

51 BIAS MODE
NO RESTRICTIONS
PROCEDURE:
ETCH MODE OFF

52 ETCH MODE
NO RESTRICTIONS
PROCEDURE:
BIAS MODE OFF

53 DEPOSIT MODE
NO RESTRICTIONS
PROCEDURE:
BIAS MODE OFF

54 IGNITION ON
RESTRICTIONS:
CHAMBER STATUS (MUST BE BELOW
TRIP (STATUS=1)

55 IGNITION OFF
NO RESTRICTIONS

56 DC ENABLE ON
RESTRICTIONS:
RF OFF
MAGNETRON OFF

57 DC ENABLE OFF
RESTRICTIONS:
RF OFF
MAGNETRON OFF

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- 58 MAGNETRON ON
RESTRICTIONS:
CHAMBER STATUS (MUST BE BELOW TRIP)
DC ENABLE (MUST BE ON)
RF (MUST BE OFF)
- 59 MAGNETRON OFF
NO RESTRICTIONS
- 60 RF ON
RESTRICTIONS:
CHAMBER STATUS (MUST BE BELOW TRIP)
MAGNETRON (MUST BE OFF)
DC ENABLE (MUST BE OFF)
- 61 RF OFF
NO RESTRICTIONS
- 62 BIAS MOTOR FORWARD
NO RESTRICTIONS
PROCEDURE:
1. BIAS MOTOR REVERSE OFF
2. BIAS MOTOR FORWARD ON
- 63 BIAS MOTOR REVERSE
NO RESTRICTIONS
PROCEDURE:
1. BIAS MOTOR FORWARD OFF
2. BIAS MOTOR REVERSE ON
- 64 BIAS MOTOR STOP
NO RESTRICTIONS
PROCEDURE:
1. BIAS MOTOR FORWARD OFF
2. BIAS MOTOR REVERSE OFF
- 65 AUTO MODE ON
NO RESTRICTIONS
- 66 AUTO MODE OFF
NO RESTRICTIONS
- 67 DGC FIL. ON
NO RESTRICTIONS
- 68 DGC FIL. OFF
NO RESTRICTIONS
- 69 DGC FIL. ON
NO RESTRICTIONS
- 70 DGC FIL. OFF
NO RESTRICTIONS

For example, if ELEVATOR UP = 0 and ELEVATOR DOWN = 1, the second line of status would look like: 'ELEVATOR: DOWN'. If both bits were 1 then the display would read: 'ELEVATOR: UP DOWN'. In actual operation, the 'UP' and 'DOWN' should not appear at the same time since the elevator cannot both be up and down. The appearance of both indicators would indicate a hardware problem. If no indications appear, the elevator is neither fully up or down.

The input status is read just before the input status page is written to the screen. To sample the input status again and update the screen, the operator must press ENTER. To return to the Main Menu Command Code Display, the operator must press 0 ENTER.

Mode 1 is identical to Mode 0 except that the display will update automatically every second. To exit Mode 1, press ENTER.

Mode 3 displays the status of all of the control bits that are output from the MPC. The display format is similar to the manual mode command list format. If a bit is 0, it is not displayed. If a bit is a 1 then the channel number and function name associated with that command is displayed. For example if WORD1 BIT6 is true (a logical 1), the message 09 MECH PUMP ON will be displayed.

After examining the display, the operator must press ENTER. If more than one page is required to display all of the messages, the display will turn to page 2, otherwise the operator will be returned to the status display menu.

Mode 4 and 5 display the analog signals which are input to the MPC as well as the DGC reading. Modes 4 and 5 are similar to the modes 1 and 2 in that mode 4 updates every second and mode 5 updates only on command.

Status Display Mode

The status display mode is used to display the status and condition of the Model 4410 System. The state of every input or output to the MPC is displayed in the status display mode.

The status display mode is entered from the main menu command mode display, (4 ENTER). When the status display mode is entered, it will display it's own menu (as shown in Table B-4). Function 0 will return the operator to the main menu.

Functions 1 and 2 are essentially the same. They display the condition of all of the digital status signals going into the MPC. The display for function 2 is shown in Table B-5. Every input bit is represented by a description on the screen. If the particular bit is true, the description will appear. If the bit is false, the description will be erased from the screen.

The screen format for mode 5 is shown in Table B-6. The analog signals are represented in volts. The first digit and the exponent of the DGC is displayed.

TABLE B-4

STATUS DISPLAY MODE

- 0 RETURN TO MAIN MENU
 - 1 DIGITAL INPUTS (SINGLE SHOT)
 - 2 DIGITAL INPUTS (REPEAT)
 - 3 DIGITAL OUTPUTS
 - 4 ANALOG INPUTS (SINGLE SHOT)
 - 5 ANALOG INPUTS (REPEAT)
-

TABLE B-5

INPUT STATUS

LOCK: AT AIR, DOOR OPEN, CLOSE, CLOSING, VALVE OPEN CLOSED
ELEVATOR: UP DOWN
CARRIAGE: IN OUT
SHUTTER IN POS.: 1, 2, 3, 4
TRIP POINTS: FORELINE, CHAMBER, LOCK, HEAT
TURBO: AT SPEED, WATER
LN SENSOR: WET
RF: ON
IN BIAS MODE, IN LOAD POSITION, IGNITED

ENTER 0 TO QUIT OR PRESS ENTER TO UPDATE DISPLAY

TABLE B-6

ANALOG INPUTS

ANALOG CH. 1	=0.000
ANALOG CH. 2	=0.000
ANALOG CH. 3	=0.000
ANALOG CH. 4	=0.000
ANALOG CH. 5	=0.000
ANALOG CH. 6	=0.000
ANALOG CH. 7	=0.000
ANALOG CH. 8	=0.000

DGC DISPLAY = OE-0

ENTER 0 TO QUIT OR PRESS ENTER TO UPDATE DISPLAY

RUNNING THE SYSTEM

Many characteristics of deposited films depend on deposition rate, which in turn depends on such parameters as power, pressure, target-to-substrate distance, target material, substrate bias, etc.

Target-to-substrate distance also influences uniformity of the thickness of the deposited films. Therefore, it is advisable to find, by trial and error, the set of parameters which will yield best results. Unlike thermal evaporation techniques, sputtering is a highly repeatable process and will yield identical results from run to run if parameters are kept constant.

Preparation for Operation

The following check list should be followed before every usage of the system.

Utilities

The following utilities should be connected and ready to go.

1. AC Power to the distribution box.
2. Cooling water
3. LN_2
4. Dry N_2
5. Argon gas
6. Power Supply connected (RF and/or DC)
7. Air Supply

Controls

The following control settings should be verified:

1. RF Generator circuit breaker turned ON.
(Green pilot light will illuminate)
2. Switch APC to AUTO
(All switches on front panel turned—off)
3. Switch lock control to Auto and all switches turned—off.
4. Turn DGC or WRG Function selector to ST1 or ST2 and switch mode selector to ARGON-AUTO.
5. Mechanical Pump and Hi-Vacuum Pump ON.

Process Chamber Controls

1. The chamber should be closed and sealed and the system pumped down. The gauge should indicate an operating vacuum of at least 5×10^{-2} Torr.
2. Mode Selector on system panel on either DEPOSIT, BIAS, ETCH, or DC depending on requirement.
3. Select target on target selector.

Operating Modes

The Model 4410 system is designed to perform a variety of sputtering and etching routines. These modes are fully described in Table 3.4-1.

Initial Start-Up Procedure

Everyday operation of the Model 4410 Sputtering System by production personnel is covered in Section 4, the Operator's Guide. This section covers procedures that should be performed by a System Engineer in support of production usage.

When the Model 4410 System is not being used, its normal standby status includes the chamber closed and pumped down to vacuum, with the high-vacuum pump operating. The chamber is vented to atmospheric pressure (by being filled with nitrogen gas) only long enough for routine maintenance.

However, at the time the system is first put into operation—or subsequently if it has been shut down (de-powered) for any significant period—the following START-UP CHECKLIST should be followed.

1. Carefully remove from the chamber any particulate or volatile materials, such as dust or metal powders, water, solvents, oil (other than high-vacuum lubricants in small quantities), organic material, etc. Such substances will circulate within the system under high vacuums potentially fouling the pumps.
2. Close the chamber if it is open by pressing the HOIST control on the automatic pumpdown control (APC) to the DOWN position. Hold it until the guide pin seats in the locating hole, and the motor stops.
3. Verify that all power and utility connections to the system are in good order, and that water and liquid and gaseous nitrogen are ready to flow when needed.
4. Check the control settings and indicators on the APC and ensure they are off or in the down position.
5. Switch the APC to automatic and make sure the back panel toggle switch is not turned to the interlock defeat position.
6. If system is equipped with a cryopump, perform a cryopump regeneration cycle if required in accordance with Section 3.2.1.2; this takes about 3½ hours. When the regeneration cycle is completed, the cryopump is restored to full operating efficiency.
7. After regeneration cycle time is completed and while the mechanical pump is still operating, initiate pumpdown sequence by switching from manual to auto and pressing START and PUMP simultaneously. (This can be done any time after regeneration is initiated.)
8. After achieving trip pressure, roughing will stop automatically, the Hi-Vac valve will open and the high vacuum pumping will commence.
9. Check the DGC reading to verify that normal operating vacuum has been achieved (refer to Section 3.3.4).

RF Deposit Calibration Run

After system start-up, the following manual procedure is used for a calibration run using RF sputtering.

1. Pump the chamber to a pressure lower than 1×10^{-6} Torr.
2. Place a clean microscope slide or suitable substrate on the pallet.
3. Load the pallet into the sputtering chamber.
4. Open the argon shut-off valve using the Automatic Pumpdown Control.
5. With the needle valve, adjust the argon pressure in the chamber to about 10 microns (1.0×10^{-2} Torr). The pumping speed is automatically throttled at the pumping port for cryopumps.
6. Turn the POWER ADJUST knob fully counter-clockwise.
7. Select a target with the TARGET SELECTOR switch; select the operating mode with MODE switch and set the SHUTTER switch to CLOSED.
8. Push the POWER ON/OFF button to turn it on.

9. Increase the POWER ADJUST keeping the REFLECTED POWER meter on scale. If no discharge appears, adjust the LOAD and TUNE control to reduce the reflected power reading. Ignition is automatic.

NOTE

DO NOT EXCEED 500 W INPUT WITHOUT DISCHARGE. IF THE DISCHARGE DOES NOT IGNITE AT 500 W, THE GAUGE MAY NOT BE WORKING PROPERLY AND THE ACTUAL PRESSURE MAY BE CONSIDERABLY LOWER THAN 10 MICRONS. IN THIS CASE, RAISING THE PRESSURE WILL HELP START THE DISCHARGE.

10. With the discharge glowing, adjust the TUNE and LOAD control for a minimum reading on the REFLECTED POWER meter.
11. Adjust the LOAD control until reflected power is less than a minimum, typically, less than 25W for 2kW forward power.
12. Turn the POWER ADJUST to a desired forward power setting and recheck the TUNE and LOAD settings for minimum reflected power.
13. If using a dielectric target or a target metal which oxidizes readily, wait until a sufficient depth of the surface layer is sputtered away (target pre-cleaning) to obtain a clean target surface. With some metals, such as chromium, the discharge will change color and the reflected power will change slightly from its initial minimum when the surface oxide is removed.
14. Set the SHUTTER switch to OPEN.
15. Turn off the discharge at the end of the desired run time.
16. Close the argon shut-off valve by depressing the PUMP button together with the START button on the Automatic Pumpdown Control.
17. Unload the pallet.
18. Evaluate the characteristics of the film deposited on the substrate and repeat the process until the best set of parameters is found.

DC Magnetron Calibration Run

The following manual procedure is used for a calibration run of DC Magnetron Deposit.

1. Pump the chamber to a pressure lower than 1×10^{-6} Torr.
2. Place a clean microscope slide or a suitable test substrate on the pallet.
3. Load the pallet into the sputtering chamber.
4. Open the argon shut-off valve using the Automatic Pumpdown Control.
5. With the needle valve, adjust the argon pressure in the chamber to about 5 microns (0.5×10^{-2} Torr). The pumping speed is automatically throttled at the pumping port for cryopumps.
6. Turn the DC POWER ADJUST knob fully counter-clockwise.
7. Select a target with the TARGET SELECTOR switch; select the operating mode with mode switch and set the SHUTTER switch to CLOSED.
8. Push the CONT POWER ON/OFF button to turn it on.
9. Increase the POWER ADJUST slowly (CW). Ignition is automatic.

NOTE

DO NOT EXCEED 500 W INPUT WITHOUT DISCHARGE. IF THE DISCHARGE DOES NOT IGNITE AT 500 W, THE GAUGE MAY NOT BE WORKING PROPERLY AND THE ACTUAL PRESSURE MAY BE CONSIDERABLY LOWER THAN 10 MICRONS. IN THIS CASE, RAISING THE PRESSURE WILL HELP START THE DISCHARGE.

10. With the discharge glowing, adjust DC power to desired power level.
11. If using a target metal which oxidizes readily, wait until a sufficient depth of the surface layer is sputtered away (target pre-cleaning) to obtain a clean target surface. With some metals, such as chromium, the discharge will change color when the surface oxide is removed.
12. Set the SHUTTER switch to OPEN.
13. Turn off the discharge at the end of the desired run, or use the timer.
14. Close the argon shut-off valve by depressing the PUMP button together with the START button on the Automatic Pumpdown Control.
15. Unload the pallet.
16. Evaluate the characteristics of the film deposited on the substrate and repeat the process until the best set of parameters is found.

**THE FOLLOWING DRAWINGS ARE REQUIRED
TO COMPLETE THIS MANUAL:**

C221-972-700	Microprocessor and Gas Cabling
D221-546-100	Cable Diagram, Microprocessor Final Assembly
C221-545-500/510	Microprocessor

Vendor manuals for the following Microprocessor
components may be purchased from Perkin-Elmer
Plasma Products Division Field Service
Department:

122-303-660	32/32 Input/Output Module #M68MM03(D3)
122-303-670	32k ROM Module #9616, Rev. B
122-303-680	A/D-D/A Converter, Sinetrac Series ST-6800 BIA
122-303-690	PC Board Module, 9600A MPU
122-303-700	Memory Module #MM-6800

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Section 1.0

GENERAL INFORMATION

1.1 Introduction

The Microprocessor Process Controller (MPC) provides a "hands-off" processing system to control production line sputtering. The only manual functions required of the operator are to load the materials to be processed and to close the load lock door; the remaining operations are controlled by the MPC system. The operator interfaces with the MPC through the Display Unit (DU), which consists of a CRT screen, a keyboard and a key lock. All commands are entered through the keyboard and displayed on the screen. The MPC can be pre-programmed to perform all the operating cycles required for specific sputtering processes.

1.2 Modes of Operation

The MPC operates in the following modes:

a. Production Sputtering

In this mode, the operator initiates the process by closing the load lock door. The MPC assumes control from that point on

b. Set-up Programming

In this mode, the system engineer turns the key lock to ENABLE and performs the following functions:

1. setting the MPC to a different process;
2. changing process parameters;
3. operating the system in the Manual mode.

c. Process Development or Maintenance

In this mode, the MPC is unlocked so that the Manual mode and status display functions can be used to develop a new process or to perform service on the sputtering system.

Section 2.0

EQUIPMENT

2.1 Introduction

The MPC is equipped with a Display Unit (DU), through which the operator issues commands to the system. The DU comprises a CRT Display Screen, a Keyboard and a Key Lock.

2.2 CRT Display Screen

Data typed on the keyboard is displayed on the screen as it is entered, permitting the operator to observe and correct entry errors.

A cursor — an underscore character (_) — indicates where the next data will be displayed on the screen. A cursor always appears on the screen when the power is on.

While the system performs its sputtering operations, messages are displayed on the screen to keep the operator informed of both normal and abnormal conditions.

2.3 Keyboard

There are 16 keys on the keyboard, 13 of which are functional. The operator should understand the meaning and use of each key fully before attempting to operate the keyboard.

a. Digit Keys (0-9)

These keys enter numeric information into the system. The digit entered is displayed on the screen at the cursor.

b. Enter Key

This key sends commands and statements entered on the keyboard to the system for execution or processing.

c. Delete Key

This key eliminates an incorrect command

or statement typed on the keyboard. It must be used before the enter key is pressed.

d. Decimal Point Key (.)

This key adds a decimal point to commands typed on the screen and is displayed at the cursor.

2.4 Key Switch

The key switch, operated with a removable key, is located to the right of the CRT display screen. It can be set to one of three positions: Lock, Enable and Reset.

a. Lock

In the Lock position, the MPC is restricted to performing a specific sputtering process selected by the system engineer while in the AUTO OPERATE mode. When the key is turned to Lock, the keyboard is disabled so that no further input can be entered. The operator then loads the substrate materials and closes the load lock door as prompted by the CRT screen to repeat the process indefinitely.

b. Enable

In the Enable position, the MPC will accept input which modifies programs already entered, initiates new programs or permits interlocks to be over-ridden so that system maintenance can be performed.

c. Reset

In the Reset position, the MPC returns to the initial start-up position. The "Main Menu," or selection of operating modes, is displayed on the CRT screen.

Section 3.0

OPERATION

3.1 Introduction

The Perkin-Elmer Microprocessor Process Controller permits automated control of machine functions and process parameters, including load lock operation, pumpdown, venting and all process sequences. Up to five 15-step process sequences can be stored in the MPC's memory to facilitate process changes.

Figure 1 shows the MPC Main Menu Command Code Display, a list of the five modes or func-

tions to be selected. The Main Menu is displayed on the screen when the operator types 0 and presses the Enter key. Each function may in turn have one or more menu displays and further sub-functions. The operator selects a function or sub-function by typing in the command code number (displayed to the left of the command) and pressing the Enter key. As the numbers are entered, they are displayed on the CRT screen. If an invalid number is entered, or if more than six digits are entered, the input is erased.

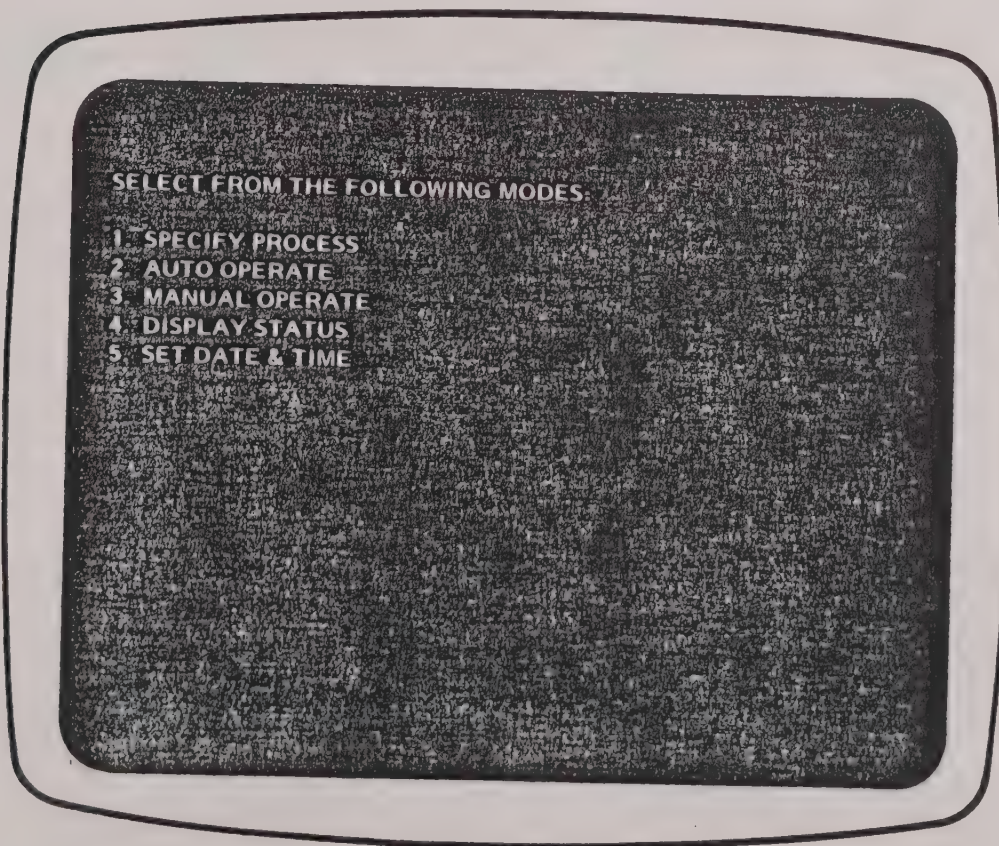


Figure 1. Main Menu Command Code Display

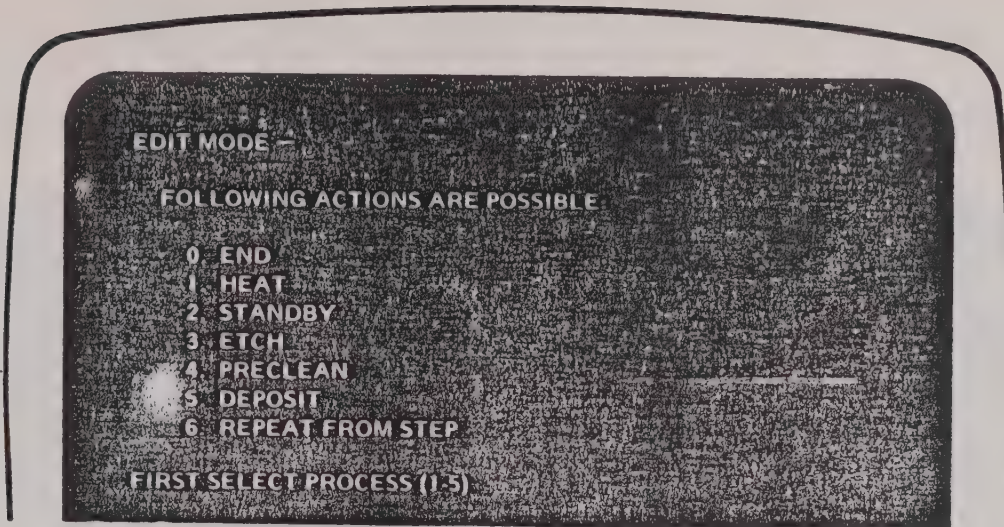


Figure 2. Specify Process Mode

3.2 SPECIFY PROCESS Mode (EDIT Mode)

Figure 2 shows the five pre-programmed processes that appear on the CRT screen when 1 from the Main Menu Command Code Display is entered. (0. END recalls the Main Menu again.)

When one of the five programs is selected, the list of process steps for that program is displayed on the screen. An example is given in Figure 3.

When the display shown in Figure 3 appears on the screen, the operator can modify, insert or delete steps in the following manner:

3.2.1 To modify steps

The operator selects the step number that indicates the process to be changed. For example, to modify the Deposit process, the operator types 3 and presses Enter. Figure 4 shows the display that results.

The cursor will appear at the first parameter to be modified: 3 —. The operator may then take any of the following actions:

- Press the Enter key to accept the displayed parameter and advance the cursor to the next line.
- Type in new data and press the Enter key.

- Type in a period (.) and press the Enter key to escape from the modify function.

When the desired command is entered, the next step is displayed and the cursor is moved to the appropriate parameter.

3.2.2 To insert or delete steps

By typing . before the number of a given step, the operator enters the Insert or Delete mode.

Insert. For example, to add a step immediately following the Deposit process, the operator types and enters .3. The Insert format, shown in Figure 5, displays the line preceding the entry point. As explained in paragraph 3.2.1, the operator may enter a new parameter or type . and press the Enter key to escape from the Insert mode altogether. Entering 0 will put an End to the program at step 3 and escape automatically.

Delete. For example, suppose the operator wishes to delete step 3, the Deposit process. Since .3 has already been typed and entered in order to call up the Insert or Delete mode, the operator need only press the Enter key again to delete the step entirely. The CRT screen responds with 03 LINE DELETED!

When the operator is finished with the selected program and has escaped by typing and enter-

STEP #	ACTION	RF/DC	TARG	POWER	DURATION	GAS	BIAS	PROCESS #
01	1 HEAT	—	—	—	—	—	—	—
02	2 STANDBY	—	—	—	—	—	—	—
03	5 DEPOSIT	—	—	—	—	—	—	—
04	2 STANDBY	—	—	—	—	—	—	—
05	6 REPEAT FROM STEP	—	—	—	—	—	—	—

Figure 3. Process Steps for a Sample Program

Note: Enter 1 for RF; 2 for DC.

STEP #	ACTION	RF/DC	TARG	POWER	DURATION	GAS	BIAS	PROCESS #
03	5 DEPOSIT	—	—	—	—	—	—	—
03	—	—	—	—	—	—	—	—

Figure 4. Step Modification

STEP #	ACTION	RF/DC	TARG	POWER	DURATION	GAS	BIAS	PROCESS #
03	1 HEAT	—	—	—	—	—	—	—
03	—	—	—	—	—	—	—	—

Figure 5. Inserting a New Step

ing . alone, the modified program is displayed on the CRT screen for inspection. If an error is detected in the display, the operator can type an escape (., Enter) from any parameter on the line indicated by the cursor to wipe out that line and hold it open for the error to be corrected. Typing another escape (., Enter) returns the **SELECT PROCESS** menu to the screen; typing an End (0, Enter) returns the Main Menu to the screen.

3.2 AUTO OPERATE Mode

The Auto Operate mode can be selected from the Main Menu Command Code Display by typing **2** and pressing the Enter key. The pre-programmed process will be executed automatically to its conclusion as long as it has an End step compiled.

The MPC scans the system and informs the operator of any abnormalities before proceeding with a process. If, for instance, the elevator is down, the carriage is out or the load lock door is locked, the operator is asked to correct these conditions. The operator calls up the Manual Operate mode from the Main Menu by typing and entering **3** to make the corrections.

When all preconditions are satisfied, the operator returns the MPC to the Auto Operate mode by typing and entering **2**. The program will prompt the operator to close the load lock door so that pumpdown can be initiated.

During the Standby and Heat processes, the pallet need not be placed in the chamber. The Standby process requires only that the load lock be maintained at the trip point, which is accomplished during the automatic pumpdown routine. The Heat process takes place in the load lock and also requires no movement of the pallet. However, in the Deposit, Etch and Preclean processes, the pallet is moved into the chamber once the Wide Range Gauge (WRG) reaches its trip point.

It is possible to go directly to any mode without intermediate preparation. If an automatic sequence has been created that requires going from Standby or Heat to Deposit and then back to Heat or Standby, the pallet will be loaded and unloaded automatically.

When the Deposit, Preclean or Etch processes are selected, the program automatically selects the preprogrammed target, moves the shutter and monitors the WRG for the programmed set point to begin the sequence. At the WRG trip, the program begins to ramp the selected sputter power source toward its set point.

As soon as that set point is reached, an internal timer is activated. The CRT screen continuously displays the time remaining in the process. At the end of the countdown, the power source is turned off and the next step is interpreted.

If the next step is an End, the pallet will be unloaded automatically. The lock vent opens when the load lock is secure. The program allows an additional 30 seconds after the load lock has reached atmosphere and then closes the vent. A message appears on the CRT screen to prompt the operator to remove the pallet. This operation resets the program and the operator is prompted to place another substrate pallet in the load lock and close the door.

The selected procedure will thus recycle indefinitely.

To escape from the process, the operator unlocks the key lock and types and enters **0**. The Main Menu Command Mode Display appears on the CRT screen.

3.4 MANUAL OPERATE Mode

The Manual Operate mode can be selected from the Main Menu Command Code Display by typing **3** and pressing the Enter key. The first of four pages of commands (see Table 1) will be displayed on the CRT screen. The operator presses the Enter key to advance to the next page; pressing the Enter key while Page 4 is displayed returns the first page to the screen.

In the Manual Operate mode, the operator can change the state of any function in the system over which the MPC has control. A series of Manual Mode Interlocks (MMI) are built into the MPC to prevent the operator from inadvertently damaging the integrity of the system.

TABLE 1
Manual Operate Mode Displays

MANUAL OPERATE MODE PAGE 1

00	RECALL MAIN MENU	12	HI-VAC PUMP OFF
01	CHAMBER VENT OPEN	13	HI-VAC VALVE OPEN
02	CHAMBER VENT CLOSE	14	HI-VAC VALVE CLOSE
03	LOCK VENT OPEN	15	THROTTLE VALVE OPEN
04	LOCK VENT CLOSE	16	THROTTLE VALVE CLOSE
05	SPARE	17	LOCK HI-VAC VALVE OPEN
06	SPARE	18	LOCK HI-VAC VALVE CLOSE
07	LOCK ROUGH OPEN	19	LOCK VALVE OPEN
08	LOCK ROUGH CLOSE	20	LOCK VALVE CLOSE
09	MECHANICAL PUMP ON	21	CARRIAGE INSERT
10	MECHANICAL PUMP OFF	22	CARRIAGE WITHDRAW
11	HI-VAC PUMP ON	23	LOCK ELEVATOR UP

MANUAL OPERATE MODE PAGE 2

24	LOCK ELEVATOR DOWN	36	SHUTTER 2 CLOSE
25	TABLE UP	37	TARGET 1
26	TABLE DOWN	38	TARGET 2
27	TABLE ROTATE ON	39	TARGET 3
28	TABLE ROTATE OFF	40	SPARE
29	SPARE	41	LN ₂ VALVE OPEN
30	SPARE	42	LN ₂ VALVE CLOSE
31	SHUTTER TO POS. 1	43	HORN ON
32	SHUTTER TO POS. 2	44	HORN OFF
33	SHUTTER TO POS. 3	45	GAS 1
34	SPARE	46	GAS 2
35	SHUTTER 2 OPEN	47	GAS 3

MANUAL OPERATE MODE PAGE 3

48	LOCK HEATER OFF	60	RF ON
49	LOCK HEATER ON	61	RF OFF
50	SPARE	62	BIAS MOTOR FORWARD
51	BIAS MODE	63	BIAS MOTOR REVERSE
52	ETCH MODE	64	BIAS MOTOR STOP
53	DEPOSIT MODE	65	AUTO MODE ON
54	IGNITION ON	66	AUTO MODE OFF
55	IGNITION OFF	67	DGC #1 FIL. ON
56	DC ENABLE ON	68	DGC #1 FIL. OFF
57	DC ENABLE OFF	69	DGC #2 FIL. ON
58	DC ON	70	DGC #2 FIL. OFF
59	DC OFF	71	SET "PALLET IN LOCK" FLAG

MANUAL OPERATE MODE PAGE 4

72	SET "PALLET IN CHAMBER" FLAG
----	------------------------------

3.4.1 Function Activation Procedure

The operator enters the two-digit "channel number" opposite the desired function as shown in Table 1. Any of the following responses can result:

- a. The command will be executed if no interlock conflicts exist and the message **OK** will appear on the CRT screen.
- b. Suppose, for example, the function **LOCK ELEVATOR UP** (23 in Table 1) is selected. While the MPC is performing this operation, the message **WORKING** is displayed on the CRT screen. **LOCK ELEVATOR UP** is one of the functions which provides a feedback signal to the MPC to indicate that the command has been successfully executed; when the MPC receives the signal, the message **OK** will appear on the CRT screen. If the signal is not received after a certain amount of time has elapsed (the "timeout interval"), the screen will be cleared and an error message, such as **UNABLE TO LOCK ELEVATOR UP**, will be displayed.
- c. If the MPC detects an interlock conflict, it displays a list of the conditions that could create the conflict (see Table 2). For example, a display that reads **14 HI-VAC VALVE CLOSE** means that the high vacuum valve is open and must be closed before the command can be executed. If no number precedes the displayed error condition, the interlock is being created by a sensor input to the MPC over which the operator has no direct control. If the command **HI-VAC VALVE OPEN** is issued and the chamber is at atmosphere, the error message **CHAMBER TRIP** will be displayed. This condition can be corrected by the command **CHAMBER ROUGH OPEN**.

3.4.2 Interlock Over-ride Procedure

Manual Mode Interlocks (MMI) are incorporated into the MPC to protect the system from accidental damage. For instance, operating certain valves in a particular sequence may have an undesirable effect such as flooding the cyropump.

However, the interlocks can be unconditionally over-ridden. The operator can take the following steps to have a selected function performed regardless of any other condition in the system:

1. Type in the two-digit channel number, followed by a decimal point. (Ordinarily, it is not necessary to type in the leading zero when working in the Manual Operate mode. To defeat an interlock, however, two digits must always be used; i.e., channel number 1, **CHAMBER VENT OPEN**, would be typed in as 01. to over-ride the interlock).
2. Press the Enter key. If any interlocked conditions exist, the MPC will respond by displaying
**THE FOLLOWING CONDITIONS
ARE INTERLOCKED OUT:
(conditions)
RE-ENTER COMMAND TO DEFEAT
INTERLOCK**
3. Re-enter the command exactly. The MPC will display
**THE FOLLOWING CONDITIONS ARE
INTERLOCKED OUT:
(conditions) OK
PRESS ENTER TO RESUME**

The command will be executed as in the standard manual mode as if no interlock conditions existed.
4. If the second command does not match the first exactly, the command will be aborted and the operator will be returned to the current display page. In that case, repeat steps (1) through (3) to over-ride the interlock successfully.

A list of Manual Operate Mode commands and interlock conditions is given in Table 2.

TABLE 2
Manual Mode Commands and Interlock Conditions

00 RECALL MAIN MENU No Restrictions 01 CHAMBER VENT OPEN Restrictions: Lock Valve Closed Hi-Vac Valve Gas Off 02 CHAMBER VENT CLOSE No Restrictions 03 LOCK VENT OPEN Restrictions: Lock Door Close Lock Valve Close Lock Rough Close Lock Hi-Vac Close 04 LOCK VENT CLOSE No Restrictions 05 SPARE 06 SPARE 07 LOCK ROUGH OPEN Restrictions: Pump On Door Close Vent Close	08 LOCK ROUGH CLOSE No Restrictions 09 MECH. PUMP ON No Restrictions 10 MECH. PUMP OFF No Restrictions 11 HI-VAC ON No Restrictions 12 HI-VAC OFF No Restrictions 13 HI-VAC VALVE OPEN Restrictions: Chamber Trip Hi-Vac Pump Chamber Vent Close 14 HI-VAC VALVE CLOSE No Restrictions 15 THROTTLE VALVE OPEN No Restrictions 16 THROTTLE VALVE CLOSE No Restrictions
17 LOCK HI-VAC OPEN Lock Door (Must be closed) Lock Trip (Must be at trip)(Status = 1) Lock Vent (Must be closed) Lock Rough (Must be closed) 18 LOCK HI-VAC CLOSE No Restrictions 19 LOCK VALVE OPEN Chamber Trip (Must be at trip) Lock Trip (Must be at trip)(Status = 1) 20 LOCK VALVE CLOSE No Restrictions	21 CARRIAGE INSERT Restrictions: Lock Valve (Must be open) Elevator (Status = Down) Carriage (Status = Out) Procedure: 1. Turn Carriage Withdraw off. 2. Wait 100 ms for relay. 3. Turn Carriage Insert on. 4. If Status = Inserted (1) then normal exit.

(cont.)

TABLE 2
Manual Mode Commands and Interlock Conditions (cont.)

5. If Timeout (interval, 8 sec.) then error exit. Normal Exit prints "OK" on screen. Turn Carriage Insert off. Error Exit: Turn Carriage Insert off. Display error message.	
22 CARRIAGE WITHDRAW Restrictions: Lock Valve (Must be open) Elevator Status (Must be down) Carriage Status (Must be in) Procedure: 1. Turn Carriage Insert off. 2. Wait 100 ms for relay. 3. Turn Carriage Withdraw on. 4. If Status = Out (1) then normal exit. 5. If Timeout (interval, 8 sec.) then error exit. Both exits turn Carriage Withdraw off.	26 TABLE DOWN No Restrictions Procedure: 1. Turn Table Up off. 2. Delay for 100 ms. 3. Turn Table Down on. 4. Delay for 5 sec. 5. Turn Table Down off. 6. Exit
23 LOCK ELEVATOR UP Restrictions: Carriage Status (Must be out) Procedure: 1. Set to raise. 2. If Status = Up (1) then normal exit. 3. If Timeout (interval, 5 sec.) then error exit.	27 TABLE ROTATE ON Restrictions: Table (Must be up) 28 TABLE ROTATE OFF No Restrictions
24 LOCK ELEVATOR DOWN Restrictions: Carriage Status (Must be out) Procedure: 1. Set to lower. 2. If Status = Down (1) then normal exit. 3. If Timeout (interval, 5 sec.) then error exit.	29 SPARE 30 SPARE 31 SHUTTER TO POS. 1 No Restrictions Procedure: 1. Shutter 2 off. 2. Shutter 3 off. 3. Shutter 1 on.
25 TABLE UP No Restrictions Procedure: 1. Turn Table Down off. 2. Wait 100 ms. 3. Turn Table Up on. 4. Delay for 5 sec. 5. Turn Table Up off. 6. Exit	32 SHUTTER TO POS. 2 No Restrictions Procedure: 1. Shutter 1 off. 2. Shutter 3 off. 3. Shutter 2 on. 33 SHUTTER TO POS. 3 No Restrictions Procedure: 1. Shutter 1 off. 2. Shutter 2 off. 3. Shutter 3 on. 34 SPARE 35 SHUTTER 2 OPEN No Restrictions 36 SHUTTER 2 CLOSE No Restrictions

TABLE 2
Manual Mode Commands and Interlock Conditions (cont.)

37 TARGET 1 No Restrictions Procedure:	49 LOCK HEATER #1 ON No Restrictions
1. Target 2 off. 2. Target 3 off. 3. Target 1 on.	50 SPARE
38 TARGET 2 No Restrictions Procedure:	51 BIAS MODE No Restrictions Procedure: 1. Etch Mode off. 2. Deposit Mode off.
1. Target 1 off. 2. Target 3 off. 3. Target 2 on.	52 ETCH MODE No Restrictions Procedure: 1. Bias Mode off. 2. Deposit Mode off.
39 TARGET 3 No Restrictions Procedure: 1. Target 1 off. 2. Target 2 off. 3. Target 3 on.	53 DEPOSIT MODE No Restrictions Procedure: 1. Bias Mode off. 2. Etch Mode off.
40 SPARE	54 IGNITION ON Restrictions: Chamber Status (Must be below trip) (Status = 1)
41 LN₂ VALVE OPEN No Restrictions	55 IGNITION OFF No Restrictions
42 LN₂ VALVE CLOSE No Restrictions	56 DC ENABLE ON Restrictions Rf off. Dc off.
43 HORN ON No Restrictions	57 DC ENABLE OFF Restrictions: Rf off. Dc off.
44 HORN OFF No Restrictions	58 DC ON Restrictions: Chamber Status (Must be below trip) Dc Enable (Must be on) Rf (Must be off)
45 GAS 1 No Restrictions	
46 GAS 2 No Restrictions	
47 GAS 3 No Restrictions	
48 LOCK HEAT OFF No Restrictions Procedure: Heater #1 off.	

TABLE 2
Manual Mode Commands and Interlock Conditions (cont.)

59 DC OFF No Restrictions	65 AUTO MODE ON No Restrictions
60 RF ON Restrictions: Chamber Status (Must be below trip) Dc (Must be off) Dc Enable (Must be off)	66 AUTO MODE OFF No Restrictions
61 RF OFF No Restrictions	67 DGC #1 FIL. ON No Restrictions
62 BIAS MOTOR FORWARD No Restrictions Procedure: 1. Bias Motor Reverse off. 2. Bias Motor Forward on.	68 DGC #1 FIL. OFF No Restrictions
63 BIAS MOTOR REVERSE No Restrictions Procedure: 1. Bias Motor Forward off. 2. Bias Motor Reverse on.	69 DGC #2 FIL. ON No Restrictions
64 BIAS MOTOR STOP No Restrictions Procedure: 1. Bias Motor Forward off. 2. Bias Motor Reverse off.	70 DGC #2 FIL. OFF No Restrictions
	71 SET "PALLET IN LOCK" FLAG No Restrictions
	72 SET "PALLET IN CHAMBER" FLAG No Restrictions

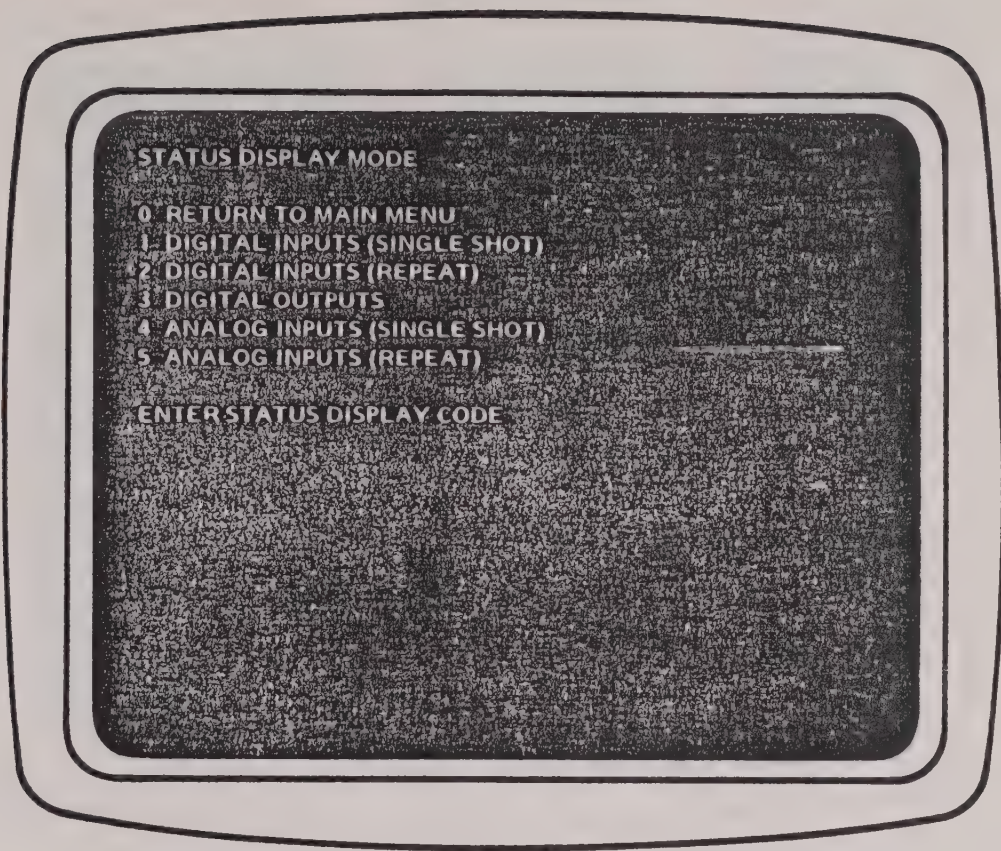


Figure 6. Status Display Mode

3.5 STATUS DISPLAY Mode

The Status Display mode is selected from the Main Menu Command Code Display by typing **4** and pressing the Enter key. Its purpose is to display the state of every input or output to the MPC, and it displays its own menu, shown in Figure 6.

Function 0 returns the operator to the Main Menu.

Functions 1 and 2 display the condition of all digital status signals going into the MPC. Figure 7 shows the list of equipment whose status will be displayed, together with all possible readings. For instance, if the elevator is up, the description of its status will read **ELEVATOR: UP**. If the elevator is down, the description will read **ELEVATOR: DOWN**. A description that

reads **ELEVATOR: UP DOWN** indicates a hardware problem, since the elevator cannot be both up and down. If neither description appears, the elevator is neither fully up nor fully down.

Function 1 displays the status as read just before the page appears on the screen. At the bottom of the display is the message: **PRESS 0 TO QUIT — PRESS ENTER TO UPDATE**. Pressing 0 returns the screen to the Status Display Mode; pressing Enter will provide an update of the status of the equipment.

Function 2 displays the status as read just before the page appears on the screen, but it updates the status automatically every second. The message at the bottom of the display reads: **PRESS ENTER TO QUIT**. Pressing Enter returns the operator to the Status Display Mode.

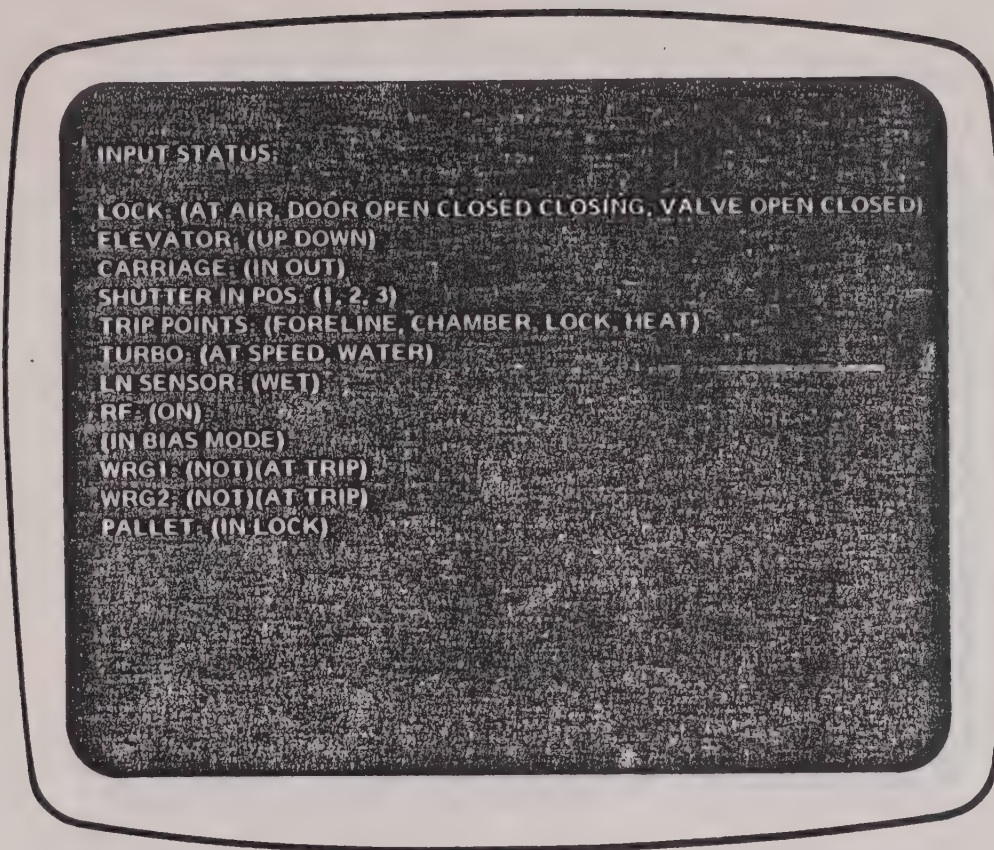
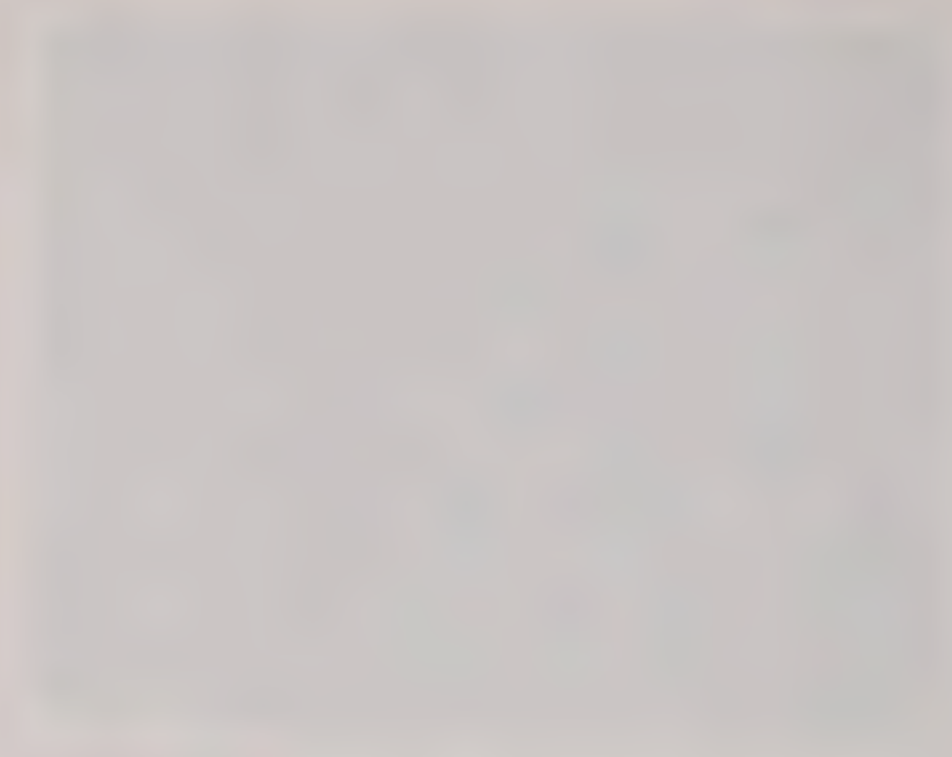


Figure 7. Digital Input Status

Function 3 displays the status of all control signals put out by the MPC in a format similar to that of the Manual Operate Mode displays shown in Table 1: **09 MECHANICAL PUMP ON**, for instance, would indicate that the MPC is presently controlling the mechanical pump. Only functions being controlled are displayed; everything else is assumed to be off. The message **PRESS ENTER TO RESUME** is displayed at the bottom of the screen. If more than one page is required to show all the digital output signals, the second page will be displayed when the operator presses Enter; otherwise, the operator will be returned to the Status Display menu.

Functions 4 and 5 display the analog signals input to the MPC as shown in Figure 8. Analog Channel 1 reports forward power (watts); Channel 2, reflected power (watts); Channel 3, substrate bias (volts); Channel 4, target bias (volts); Channels 5-8 are spares. Functions 4 and 5 are similar to functions 1 and 2 in that function 4 updates only on command and function 5 updates every second. The messages at the end of the displays correspond to those described for functions 1 and 2.



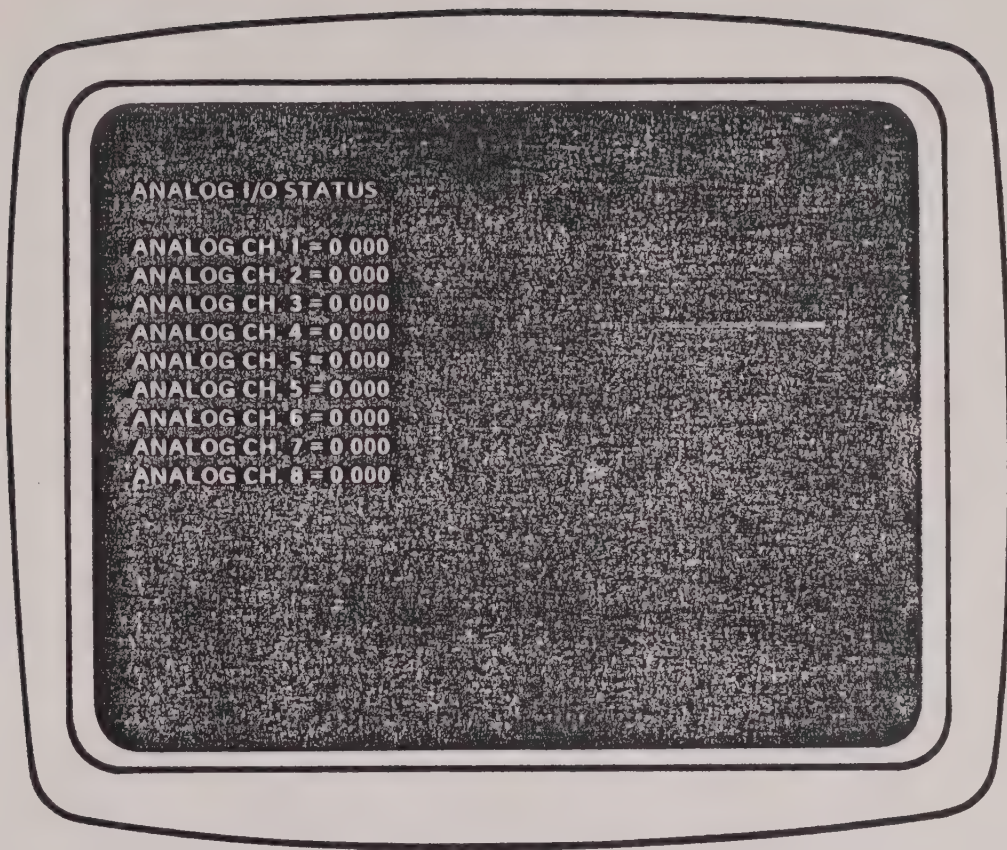


Figure 8. Analog Input Systems

3.6 SET DATE & TIME Mode

The Set Date & Time mode can be selected from the Main Menu Command Code Display by typing 5 and pressing the Enter key.

The MPC responds with the message **DATE (MMDDYY) =**. to enter the date, the operator types in a two-digit month, two-digit day and two-digit year. For instance, January 4, 1984 would be entered as **010484**.

The next prompt reads **TIME (HHMMSS) =**. Since the MPC recognizes a 24-hour clock, the operator types in a time-of-day of 2:30 pm and 32 seconds as **143032**. A time-of-day of 2:30 am and 32 seconds is typed in as **023032**.

When the operator presses the Enter key, the date and time are entered into the MPC and displayed at the Main Menu. Both are continuously updated and will need to be reset only after a power failure.

Section 4.0

SIMPLIFIED FLOW DIAGRAM



8" RF ROUND CATHODE ASSEMBLY

CAUTION

To prevent contamination of the sputtering target, insulator or backing plate, do not handle with bare hands. Use clean rubber or plastic gloves.

1. Place the cathode/target face down on a clean sheet of lint-free paper and screw the specially provided set screw into the center hole of the backing plate.
2. Inspect the side facing up for cleanliness. Remove any particles of dust, etc. from the sealing surface (Figure 1).
3. Install a lightly greased O-ring (standard size No. 258 for the 8" cathode) in the groove in the insulator center hole.
4. Hold the insulator with the machined detail facing down (Figure 2) and install insulator on the target holder. Push the insulator down until it sets against the back side of the cathode/target (Figure 3).

WARNING

Make sure not to cut or roll the O-ring (Figure 3).

5. Install a No. 210 O-ring in the inner groove and a No. 252 O-ring in the outer groove of the cover plate (Figure 4). The cover plate is also known as the brass top cap.

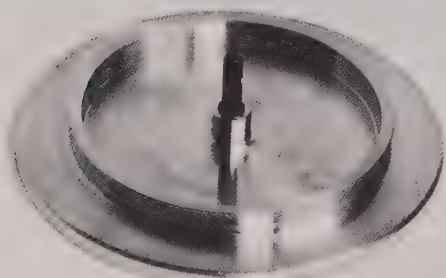


Figure 1. Cathode/Target Assembly



Figure 3. Correct Installation of Insulator



Figure 2. Installing Insulator on Cathode/Target Assembly

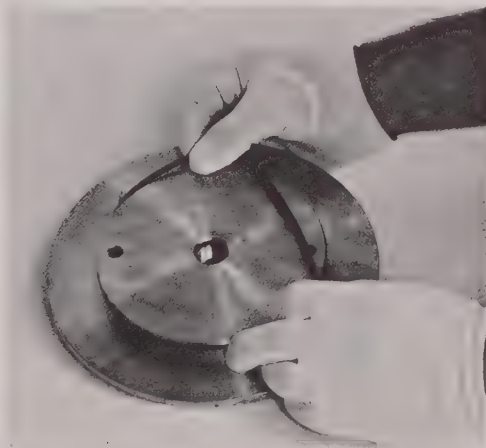


Figure 4. Installing O-ring in Cover Plate

6. Install the cover plate onto the holder/insulator assembly, making sure O-rings are not damaged. Secure assembly with a thumb nut on the # $\frac{3}{8}$ -16 thread. This thumb nut also serves as an adjustment for target position to compensate for various thickness of target materials (Figures 5 and 6).
7. Install snap ring in groove on # $\frac{3}{8}$ -16 screw. This prevents backing the target out far enough to break the water seal.
8. Install a No. 268 O-ring in the insulator groove.
9. Install target assembly in the target hole, keeping the #10 screw hole in the cover plate near the RF strap leading from the matching network.
10. Connect cooling water lines to the target.
11. Connect RF strap to the target using a #10 thumbscrew.



Figure 5. Installing Cover Plate on Holder/Insulator Assembly

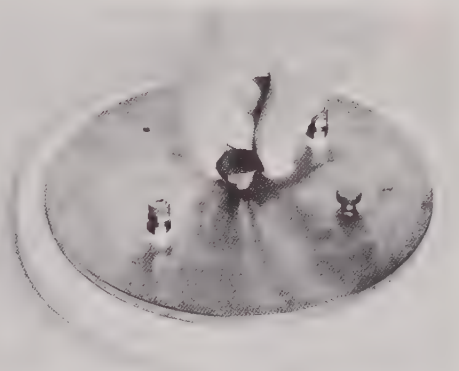


Figure 6. Locking the Cover Plate on the Target Assembly

8" DC ROUND MAGNETRON CATHODE ASSEMBLY

CAUTION

To prevent contamination of the sputtering target insulator or backing plate, do not handle with bare hands. Use clean rubber or plastic gloves.

1. Place the backing plate assembly with bonded target face up on a clean sheet of lint-free paper.
2. Inspect the side facing up for cleanliness. Remove any particles of dust, etc. from the sealing surfaces.
3. Install a lightly greased O-ring (Viton 2-266, P/N 121-396-700) in the insulators inside O-ring groove.
4. Set the insulator adjustment support ring down over the target and onto the backing plate. This is designed to be a very loose fit. (Figure 1)
5. Hold the insulator with the machined detail facing up and install over the target pressing it down on the backing plate until it sets against the adjustment support ring. (Figure 2)

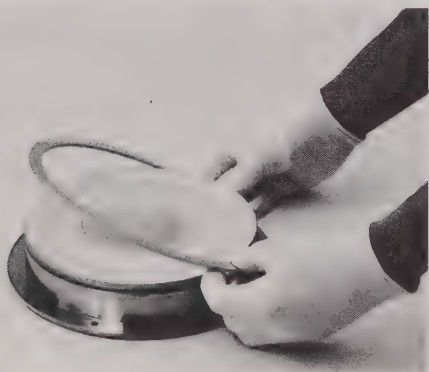


Figure 1 Installing Insulator adjustment support ring



Figure 2 Installing Insulator on cathode/target assembly.

WARNING

Do not touch the surface of the target material. Also, make sure not to cut or roll the O-ring over the target material.

6. Install an O-ring (Viton 2-228, P/N 122-140-200) in the inner groove and an O-ring (Viton 2-259, P/N 120-018-000) in the outer groove of the brass cover plate. (Figure 3)
7. Turn the backing plate assembly with insulator installed over, with the target now face down.
8. Install the cover plate onto the backing plate assembly, making sure the six screw holes line up with the holes in the cover plate. (Figure 4)
9. Install the six 1/4-20 socket-head screws (1/2 inch long, P/N 172-176-000) and carefully tighten to ensure the cover plate sets without pinching an O-ring.
10. Hold the magnetic assembly with the center protruding pole piece down. Gently set the magnetic assembly down over the cathode assembly, making sure the water lines fit through the magnets. (Figure 5)

CAUTION

Don't hold the magnetic assembly with your fingers between it and the cathode assembly, when installing, an injury can occur when the magnetic field picks up the cathode.



Figure 3 Installing O-ring in cover plate

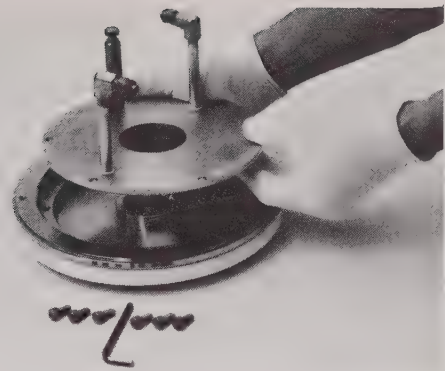


Figure 4 Installing Cover plate on cathode/target assembly.

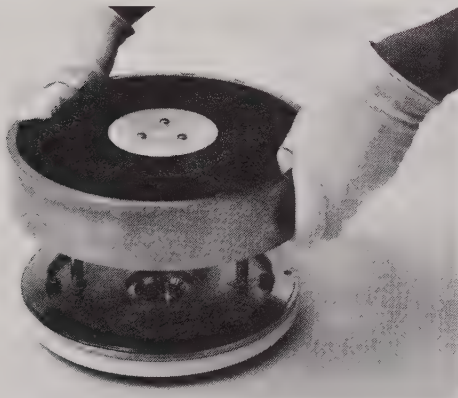


Figure 5 Installing magnetic assembly on cathode/target assembly.

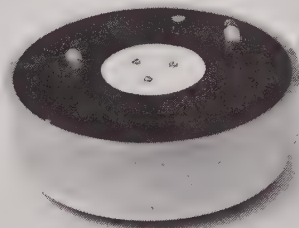


Figure 6 Complete DC magnetron cathode/target assembly.

11. Install the three ¼-20 socket head screws (1.5 inch long, P/N 176-013-000) in the backing plate. Tighten only to the point at which they touch the adjustment support ring. These screws serve as an adjustment for target position, to compensate for various thicknesses of target materials.
12. Before installing the cathode assembly in a system, turn the completed assembly back over and install an O-ring (Viton 2-269, P/N 121-397-000) in the outside insulator O-ring groove.

DELTA DC MAGNETRON CATHODE ASSEMBLY

Seal Surfaces

1. Inspect the seal surface on the insulator, the anode, and the backing plate for nicks and scratches. Polish them, if any, with 320 grit emory cloth, making sure not to spot polish. Work at least 3 inches to each side of the blemish and use 3M scotch brite to finish buff.
2. If either the backing plate or the anode is accidentally dropped or hit against another object, place it on a flat surface with the seal surface facing up to measure for Total Indicator Run-out (T.I.R.). If the T.I.R. is more than .008 of an inch on the backing plate, it should be returned to Perkin-Elmer for repair.
3. Evidence of distortion and warps can be detected by placing the insulator on a flat surface and pressing the edges to see if any noticeable rocking occurs. Also, the insulator should be checked for any evidence of melting or burning and replaced if necessary.
4. O-rings may be kept in service as long as they are not burnt and fit tightly in the insulator grooves.

Installing Pole Pieces and Magnets Into Backing Plate

1. Hand install pole pieces with beveled edge down into the backing plate. If they should require any mechanical assistance during installation into their channels in the backing plate, return backing plate and pole pieces to Perkin-Elmer for repairs. Pole pieces and backing plates are matched sets, and should not be interchanged with parts from other delta cathodes.
2. When the pole pieces are installed into the backing plate, lower the magnets into the backing plate. The pole pieces may rise and fasten to the magnets. This condition is normal. Continue pushing down and gently rock the magnet until all parts are seated properly. If necessary, remove all pieces from the backing plate and start over again.
3. When the pole pieces and magnets are in their proper place, use the screws provided to attach them tightly to the backing plate. It may be necessary to slightly shift the magnets to the openings.

Steps 1 through 3 should be performed manually only. DO NOT use other method or tools.

Installing O-rings on Insulators

1. Wipe insulators with methonal and allow them to dry.
2. Lightly coat the o-rings with vacuum grease.
3. Lay the insulator on a flat surface, hook one radius of the insulator with an o-ring and feed it into the groove. Do not scratch or roll the o-ring.

Installing Cathode Assembly into Head

1. As shown in Figure 1, place on insulator with o-rings on the bottom side of the anode and install this assembly into the sputter module cathode hole (Figure 1).
2. Place a second insulator with o-rings on top of the anode (Figure 2).
3. Insert the installation tool into the cathode assembly and double check that it is locked into place. Lift and install the cathode assembly into the second insulator on the anode. Remove tool after installation is complete (Figure 4).
4. Using your hands, first pull back on the anode and then pull back on the cathode to properly locate cathode assembly into position (Figure 5). Pump the vacuum system down. Check leak rate to assure that it meets spec. It may be necessary to shift the whole assembly and re-pump. If this fails, repeat all of Step 3. An attempt to operate the system with a leak in this area may cause extensive failure of the complete Cathode Assembly and Power Supply.
5. Install water lines onto Anode Backing Plate (Figure 6).
6. Install electrical wire onto anode and insure that the connection is tight (Figure 6).
7. Install stand off and power line onto backing plate and insure that the connection is tight (Figure 6).



Figure 1 Installing bottom insulator on anode onto sputter module.



Figure 2 Installing top insulator on anode.

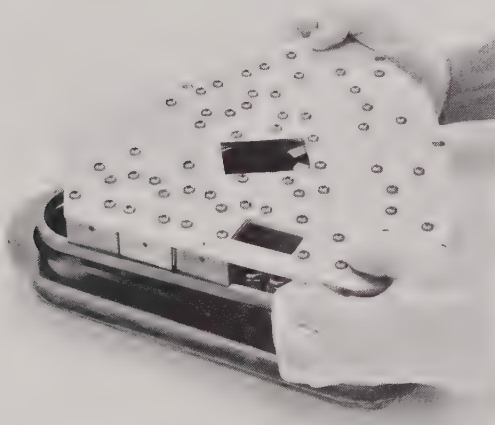


Figure 3 Installing magnets and pole piece assembly into backing plate.



Figure 4 Installing cathode into system with installation tool.

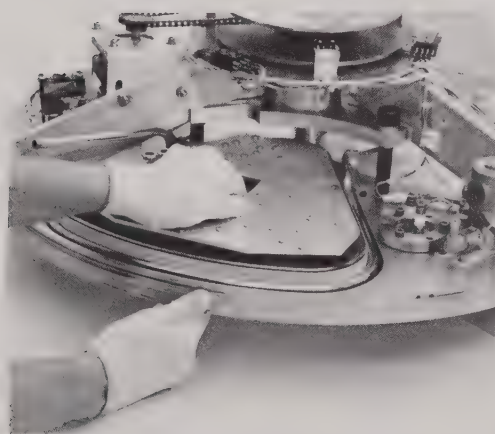


Figure 5 Position cathode by pulling out on assembly.

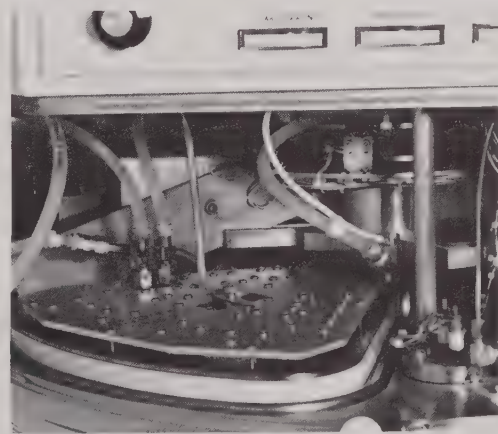


Figure 6 Complete cathode assembly with water and varo strap connected

Start-up and Burn-in Procedure

1. Turn on water supply and check for leaks after 30 minutes.
2. Place outside covers on sputter module.
3. Initiate load sequence with a bare pallet. After it is loaded, turn gas and power supply on. Operate target at a low power, 1 to 2 kw, at 5-minute intervals and increase power as the arcing subsides. New cathodes may arc for the first 20 to 45 minutes of operation. After burn-in, remove bare pallet and return system to service.

CAUTION

Operating at a high power with arcing will cause failure and severe damage.

CLEANING RESIDUAL DEPOSITS

The first step is to turn off the DC and RF power supplies, removing all electrical power in the sputtering module. Vent the sputtering module (done by pressing START and VENT buttons simultaneously on the Automatic Pumpdown Controller) to atmosphere and open chamber by pressing the "Hoist" rocker switch to UP. Due to a vacuum sensing interlock switch in the circuit, the hoist will not operate if the chamber is not fully vented.

Remove the full circle shutter, vane shutters, cross-contamination shields and dark space shields from the module. Unbolt and lift out the split-ring horizontal deposition shield that is supported on the chamber wall brackets. Coil the vertical chamber wall deposition shield and lift it out. Clean them by beadblasting or another suitable method. Etch cleaning (chemical) is not recommended because deposits often have lower etch rates than the material comprising the dark space shields (stainless steel). This results in deposits being left untouched and the shields being seriously eroded on spots where there were no deposits. Vapor degreasing or an acetone and alcohol wash after beadblasting is recommended.

While the chamber shields are removed, the viewport protector glass (P/N 122-153-700) can be replaced. By removing the retaining spring on the inside of the viewing port, the inside glass can then be taken out and replaced. A small loop of masking tape around one finger will stick to the glass and make removal easy.

WARNING

The viewport protector glass is fragile and will cut through gloves. Please handle with care.

If the inside of the chamber is to be cleaned, it would also be advisable to clean the meissner trap. The Load Lock Controller "Pallet" switch should be in the "Up" position and the "Manual Interlocked" mode. This will raise the substrate table and give enough clearance to reach the inside of the meissner trap.

MECHANICAL PUMP

Leybold Heraeus D60A

The following oil change procedure should be the only preventive maintenance ever necessary on the Leybold Heraeus D60A mechanical pump.

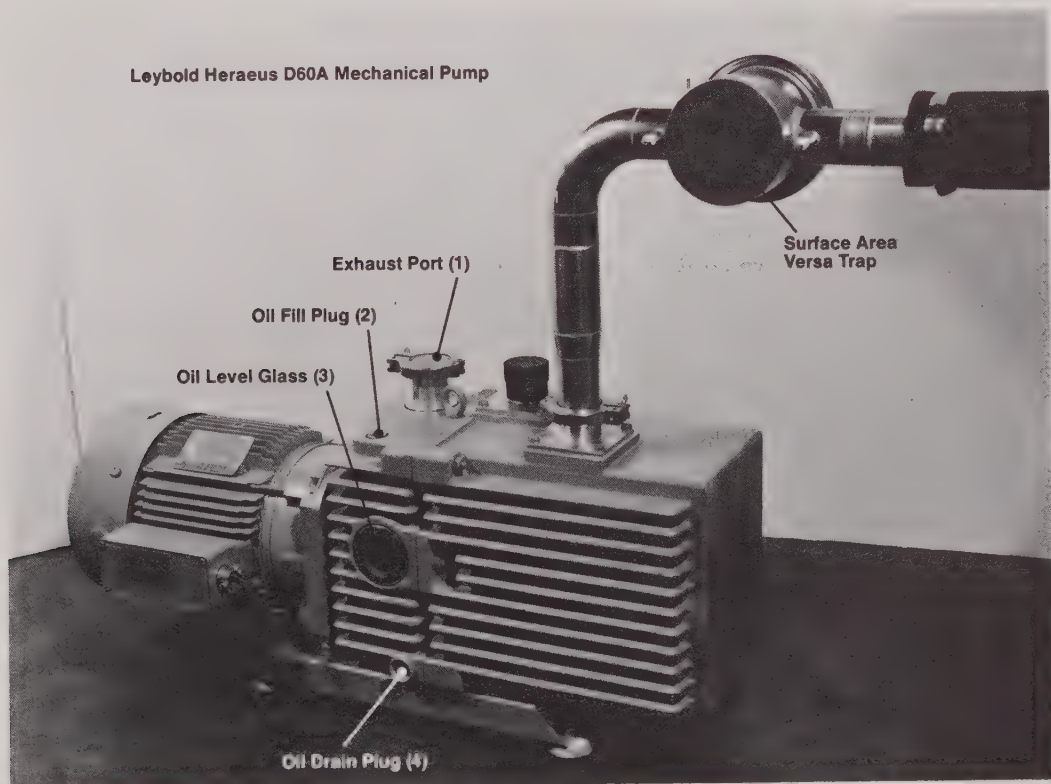
According to the manufacturer, the first oil change must be performed after 100 hrs. of operation. Under certain circumstances, a check may indicate that the oil must be changed earlier, if for instance the oil has lost its original color.

Always carry out an oil change when the pump is still warm and switched off. Unscrew the oil drain plug (4) and allow the oil to drain off. When the flow of oil slows down, briefly cut in the pump—cut out again—and drain off the remaining oil. Replace the oil drain plug (4) and fill with fresh oil at (2).

The only recommended oil for this pump (D60A) is Leybold Heraeus #HE175. The oil level is checked through the oil level glass (3), with the pump running. Maximum, fill to the top of the sight glass and minimum to the bottom of the sight glass.

A practiced procedure in the field has been found to be helpful. Always refill the pump to a level half-way up the sight glass (checked while pump is running) and then daily look for the following changes:

1. Foam or bubbles above oil level; could indicate a vacuum leak or pump problem.
2. Color of oil; could indicate contamination or normal dirt requiring an oil change.



SURFACE AREA VERSA TRAP

The Perkin-Elmer Surface Area trap contains a metallic absorbant material as the trapping medium. This model offers a low cost, low maintenance trap for trapping backstreaming pump oil without trapping water vapor.

Under normal operating conditions, the Surface Area trap cleaning can usually be done during the scheduled oil change in the mechanical pump.

The trap contains a roll of copper mesh which can either be cleaned or replaced. The trap is located between the mechanical pump and the roughing valve. Before copper mesh is removed, the line must be vented by loosening the wingnut on the quick-disconnect flange, at the mechanical pump. After the line is vented, the trap insert can be taken out by removing the quick-disconnect clamp on the trap body.

The copper mesh should be cleaned by a simple vapor degreasing or acetone and alcohol wash method.

After cleaning, it is important to let the copper mesh dry completely before re-installing. Any leftover chemical residue and/or wet alcohol will disable the mechanical pump. This would make the pump to appear as if it was not pumping during a roughing mode.

NOTE

A Surface Area Versa-Trap can be seen in the Mechanical Pump section photo.

PALLET, CARRIAGE & LOAD LOCK CHAMBER

After an extended period of time, the system pallet will become heavily coated with material and require cleaning. Clean the pallet by beadblasting or another suitable method. Etch cleaning (chemical) is not generally recommended because deposits often have lower etch rates than the material comprising the pallet (moly). This results in deposits being left untouched and the pallet being seriously eroded on spots where there were no deposits. Vapor degreasing or an acetone and alcohol wash after beadblasting is recommended.

The load lock chamber and carriage assembly are another important part of the system that will require periodic cleaning. This can easily be accomplished during a scheduled periodic maintenance.

First, with the load lock door all the way open, switch the "Lock Control" panel to the "Manual Interlocked" mode and then the "Carr" switch to the center position. This will now allow the pallet carrier to be removed without the transport mechanism operating when the carrier leaves the "Out" position microswitch.

The carriage can now be vapor degreased or acetone and alcohol washed. This should be the only type of cleaning required, since the carrier never sees a plasma.

With the pallet and carrier removed from the load lock chamber, access for cleaning is no problem. Due to possible broken wafers and silicon chips being dropped into the load lock chamber from the loading and unloading of a pallet, the load lock chamber should be vacuumed before further cleaning takes place.

Again, since the load lock chamber never sees a plasma, a simple acetone and alcohol wash should be a sufficient cleaning method.

It is very important to ensure that the pallet, carrier, and the load lock chamber is completely rinsed and totally dry before trying to operate the system. If they were still wet, the load lock chamber would not pump down. This would make the mechanical pump appear as if it was not operating correctly.

CARE OF LARGE O-RINGS

Specifically, three O-rings which should be inspected during normal maintenance are:

- | | |
|---------------------------|-----------------|
| 1. Vacuum Chamber O-Ring | P/N 121-398-400 |
| 2. Load Lock Valve O-Ring | P/N 122-149-900 |
| 3. Load Lock Door O-Ring | P/N 122-150-000 |

Both the O-ring surface and the metal sealing surface for the O-ring should be inspected for possible sealing problems. This would include dirt, wafer chips, flaking material from excess deposition deposits, cuts or scratches and alike. Any of the above could prevent proper sealing of the O-ring with an end result of a vacuum leak.

Vacuum Chamber O-Ring

During a normal cleaning of the chamber, (shutter, shields, substrate table, etc.) if the chamber O-ring is not adequately protected, particles can fall into the O-ring groove. If left unattended, these particles will eventually get on a sealing surface and cause a vacuum leak.

In some cases it may become necessary to remove the O-ring to clean it and the O-ring groove out. If acetone and alcohol are used to clean out the O-ring groove, be sure the area is completely dry before re-installing the chamber O-ring. This O-ring will appear to be too small for the chamber diameter and is normally stretched by hand before re-installing.

Load Lock Valve O-Ring

The load lock valve O-ring can be inspected, and if necessary, changed without removing the assembly from the load lock chamber. The valve must be opened manually (with the load lock controller in the "Manual Interlocked" mode and the "Lock Valve" switch in the "Open" position) and inspected with an inspection mirror for a complete check. If the O-ring requires changing, a flat "Duck Bill" type of tweezers should be used to prevent damage to the valve and the O-ring during removal. Gloves should be used at all times while working inside the system chambers). When installing a new O-ring, start from one corner of the O-ring groove. Hold the O-ring in the groove at one corner with one hand and continue on around the O-ring groove pressing the O-ring in place with the second hand.

Load Lock Door O-Ring

The load lock door O-ring can actually be inspected any time the lock door is opened to load a run. Cared for properly, this O-ring will seldom, if ever, need changing. The important things to remember are to keep the surface of this O-ring clean and ensure that the sealing surface on the load lock chamber is free of wafer chips, particles etc. and wiped off daily.

The load lock door O-ring groove is provided with a recessed area, on all four sides, for easy O-ring removal, if this becomes necessary. Installation of a new O-ring can be accomplished in the same manner as the load lock valve O-ring.

ADDITIONAL SYSTEM CARE

The following inspections should be performed in every preventative maintenance check.

1. Full circle shutter drive mechanism on sputter module top plate. Make sure clamp and gear on shutter shaft is tight; all set-screws on couplings, gears and shafts are tight; and all chains and/or gears are properly aligned.
2. Drive motor for substrate table up/down motion. Inspect drive belt for wear and proper tension and make sure the set-screws on drive pulleys are tight.
3. Drive motor for substrate table rotation. Inspect drive belt for wear and proper tension and make sure the set-screws on drive pulleys are tight.

NOTE

The table rotation drive belt can only be replaced by removing the substrate table assembly. Therefore, whenever the substrate table is removed for maintenance, inspect drive belt to make sure it does not require replacing.

PREVENTIVE MAINTENANCE - 4400 SERIES

This notice is to inform you of Perkin-Elmer's recommended maintenance interval on the 4400 Series Production Sputtering Systems.

WEEKLY

- 1) Check servo-match operation.
- 2) Clean all ground shields in chamber as needed.
- 3) Clean shutter and pallet as needed.
- 4) Check continuity of ignitor filaments; visually check filaments.
If either loop is broken, replace both loops.
- 5) Check water connections for leaks.
- 6) Daily zero and calibrate thermocouple and thermistor gauges.
- 7) Daily zero and calibrate ion gauge.
- 8) Remove ground rings on targets and clean as needed.
- 9) Assure that chains and bearings in both lock and sputter chamber drive rail assemblies are properly aligned.
- 10) Check hinge assembly on lock door for safety.
- 11) Clean and grease O-ring in load lock valve door.
- 12) Clean and grease load lock door O-ring.
- 13) Check alignment of pallet/carrier to drive rails assemblies, sputter table, carriage stops, and lock elevator.

MONTHLY

- 1) Check all interlock operations

THREE MONTHS

- 1) Examine all finger stock associated with table etch mode.
- 2) Check pressure levels on the compressor.
- 3) Change turbo pump oil.

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P. 2 of 2

3-Month, continued:

- 4) Check contacts on mode and target selector switches; if burned, replace.
- 5) Clean table.
- 6) Apply chassis grease to Acme screw of table elevator
- 7) Apply oil to chains external of vacuum which drive rail assembly feedthroughs.

SIX MONTHS

- 1) Tighten all mechanical connections on servo drive. Tune motor, (limit switches, set screws, etc.).
- 2) Replace O-rings in water manifold of the table.
- 3) Lubricate and oil hoist with chassis grease.
- 4) Change mechanical pump oil.
- 5) Replace all timing belts, if necessary: a) table rotate
b) table raise/lower

YEARLY

- 1) Replace O-ring on lock valve and O-ring on the lid.
- 2) Disconnect and clean all RF connections on the head. Replace RF switch if indicated.
- 3) Retune generator and replace tubes if necessary. Change RF pot and switch if necessary.
- 4) Replace seals on cryo pump piston after 9,000 hours. Recharge.
- 5) Check and clean water wheel assembly on water flow switches.
- 6) Replace ALL water lines on head and water fitting. (Since water lines are difficult to replace, suggest changing only if clogged).
- 7) Replace dry liner in cryo compressor after 9,000 hours. Recharge.
- 8) Replace O-rings on all differentially pumped seals:
 - a) lock
 - b) table
 - c) shutter
- 9) Recalibrate partial pressure analyzer (PPA).
- 10) Check multilam in RF contact at table shaft. Replace if required.
- 11) Remove table pallet after purging water lines. Clean ground shield, and, if required, the insulator.
- 12) Apply a dab of Apiezon "K" lubricant to conductor shaft where multilam rotates the contacts during table rotation.

ALUMINUM-SILICON SPUTTER DEPOSITION

L.D. Hartsough and D.R. Denison

It was found that high deposition rates and clean vacuum are the most important parameters in the production of optimal quality aluminum-silicon alloy films. Hydrogen and water vapor were found to strongly affect film morphology. Oxygen and nitrogen affect hardness and resistivity. Process and system capabilities required to deposit high quality films are described.

The usefulness of sputtering as a technique for aluminum metalization of semiconductor devices is well documented.¹⁻⁵ Development of the DC magnetron source has eliminated the two main problems associated with sputtering: low rate and energetic electron bombardment of the substrates. However, despite the immediate advantages sputtering can offer in terms of alloy deposition control and process flexibility, the presence of a plasma, as a source of energetic particles and as a chemical factory that can turn relatively harmless gas species into chemically active fragments, causes the total process to be more complex than evaporation. To obtain the high quality films that sputtering can provide, it is necessary to understand and control those parameters that influence film quality.

The key to understanding aluminum and aluminum alloy sputter deposition is in understanding the relationships between the set of independent variables, those parameters that are under our control, and the film parameters that result, the dependent variables. The independent variables at our disposal include target power, gas pressure, geometrical parameters such as cathode-to-substrate distance, use of uniformity shapers, and target shape, vacuum quality as determined by the residual gas composition, and substrate motion. In a loadlock system, the total vacuum quality can be affected by the method of lock pumping and substrate processing, if any, prior to loading substrates into the main vacuum environment. The dependent variables we wish to influence include step coverage, deposition rate, specularly, uniformity, film temperature, mobile ion

and energetic particle damage, resistivity, film alloy content and distribution, and bondability. These five independent and nine dependent variables give a sense of the magnitude of the problem of understanding which interrelationships are critical, which are desirable, and which are unimportant.

The sputtering system used to investigate the interrelationships between the dependent and independent variables was a Perkin-Elmer Model 4410. This system, which uses a rotating table and large area, Delta™ targets, permits maximum control of the independent variables over a wide range of conditions. No other system currently available can achieve the vacuum quality or the flexibility in varying the substrate motion as this one.

To investigate these interrelationships, an aluminum silicon delta shaped target with 1.2% silicon in 99.999% pure aluminum was used. The binary aluminum-silicon alloy was selected because during deposition it tends to form hillocks which degrade the film specularly. It is known that the addition of a ternary component, such as Cu, Mg, Ti, etc., can suppress hillock formation.⁶ However, the binary system affords an excellent means for the investigation of the sputtering process since those independent variable conditions which maximize the film quality for this sensitive alloy should also provide optimum conditions for deposition of the less sensitive ternary alloys.

The data presented here were from films made in our applications laboratory, except for measurements on film hardness and bondability, which were obtained through the courtesy of people in various semiconductor fabrication and research facilities. Data obtained from outside sources will be identified even though the specific contributor may wish to remain anonymous. The results presented in this report are organized by film characteristic with discussion of those independent variables which influence it. Not all of the dependent variables, or film parameters, are uniquely related to the independent variables, or machine parameters. For example, step coverage, film temperature, and sheet resistivity are related through the deposition rate.

As was stated before, the target contained 1.2% silicon. This level is more than sufficient for all current semiconductor processes requiring silicon doping of the aluminum metalization. At 500°C,

the solubility of silicon in aluminum is 0.8 weight percent. Thus, even when devices are thermally processed at 500°C, 1% silicon would represent excess silicon. Except where some extenuating circumstance requires a high silicon level, 1 or 1.2% silicon is more than a user needs to prevent "spiking" in shallow junction devices. Distribution of the silicon in the film will be discussed later in this paper, but it should be noted here that excess silicon can result in segregation in the film and difficulty in etching.

Utilization and Rate

Deposition rate is a function of target power, gas pressure, and system geometry. A way of looking at the interaction of these variables is to consider the relationship between specific rate, i.e. rate per unit power—such as angstroms per minute per kilowatt, and sputtered material utilization. Sputtered material utilization is defined as the fraction of the material sputtered from the target that is deposited on the substrate carrier or pallet. As an example, to have 80% sputtered material utilization only 20% of the material sputtered from the target is lost on shields, shutter, etc.

NOTE: Sputtered material utilization is NOT equal to the target material utilization which tells what percentage of the target material is removed during sputtering. The Delta target can achieve 35% to 40% target material utilization compared to 25% to 30% utilization for round or rectangular targets.

For a given cathode to substrate distance, the sputtered material utilization will vary with pressure. As the pressure is increased, scattering is increased and additional material is lost to the shields so that the utilization, and, hence, specific rate *decreases*.

Figure 1 shows the sputtered material utilization and specific rate, for a Delta cathode-to-substrate distance of 2.5 inches, as a function of pressure. It is seen that the specific rate can be in excess of 200 Å/kW-min. The specific rate is the effective rate over the entire annular pallet even though the deposition occurs on only a portion of the pallet at any instant. This can be related to a static, or instantaneous, rate of as high as 12,000 Å/minute. The Delta target is about equal to a 60° sector of the annular pallet and can be powered to 10 kW. Thus, the instantaneous rate is approximately 6 times the specific rate times the power applied. The rate data were generated with the system configured to achieve better than $\pm 7\%$ uniformity over a six inch width on the rotating annular pallet.

Uniformity

Uniformity is a geometrical parameter which interplays with specific rate and material utilization. In principle, any percent uniformity can be achieved by adjusting the deposition profile. If parts of the deposition material are intercepted, uniformity across the substrate pallet can be made as good as one wishes. The price to be paid is that as the uniformity is improved, it is done at the expense of

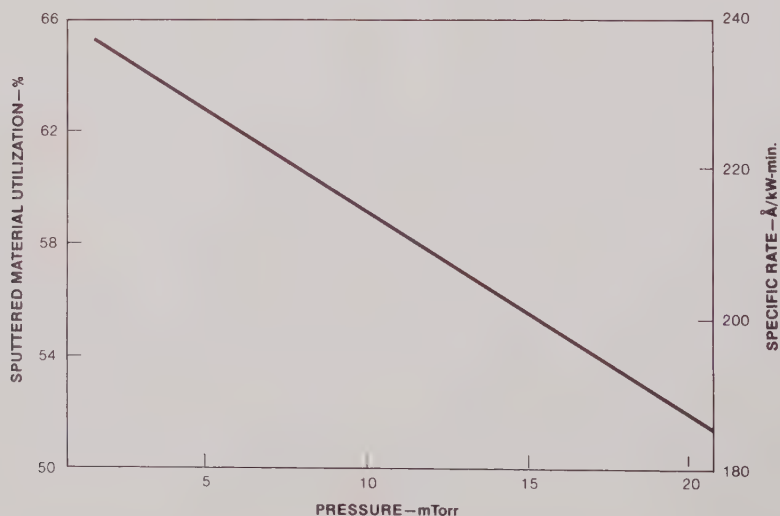


FIG. 1 Sputtered material utilization and rate as a function of argon gas pressure at a cathode-to-substrate distance of 2.5 inches.

rate and material utilization. The intrinsic uniformity with high material utilization is $\pm 7\%$ over a six inch annular width. The profile is shown in **Figure 2**.

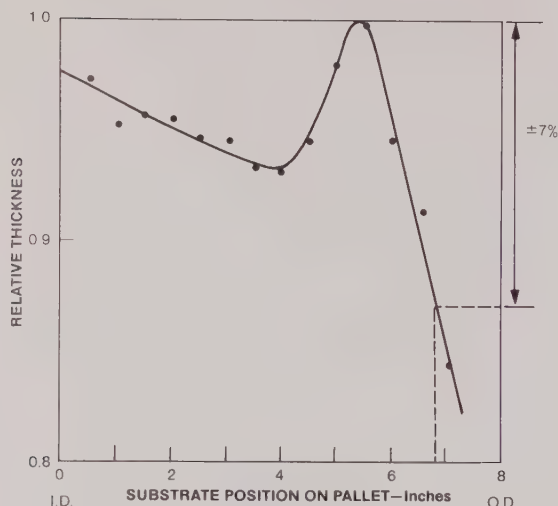


FIG. 2 Uniformity profile radially across the annular pallet.

Resistivity

Film resistivity is a function of target quality, vacuum quality, and those parameters that maximize the deposition rate. The target material must be free not only of metallic contaminants, but also of contamination by oxygen and nitrogen. A hundred parts per million oxygen is sufficient to result in aluminum films with resistivity too high to be very useful. Assuming targets of good quality are at hand, the resistivity of the film is dependent on the ability to deposit films with oxygen and nitrogen contamination not exceeding about 10 parts per million. The poorer the vacuum quality, the higher must be the rate to keep the contamination within acceptable limits. For example, if the partial pressure of a contaminating gas is 1×10^{-6} Torr, its arrival rate is about equal to one monolayer per second. Further, if its sticking coefficient is 0.01 the film arrival rate must be 10^3 layers per second to ensure a contamination level of less than 10 ppm. Because the highest rates achievable with magnetron sputtering are an order of magnitude less than this, the partial pressures of potential contaminants must be around 1×10^{-7} Torr.

Resistivity, then, is seen to be a function of target power, pressure, and vacuum quality. Target power and argon pressure affect resistivity by their influence on deposition rate. Substrate motion is

not a factor in itself, although, if vacuum quality is sufficiently poor, a slow substrate motion may be necessary to deposit the aluminum in a single pass so that the rate is high enough to keep the contamination within acceptable limits.

A resistivity of $2.8 \pm 0.1 \mu\Omega\text{-cm}$ was obtained with a system background pressure less than 5×10^{-7} Torr, an instantaneous deposition rate exceeding 8500 Å/min, and table rotation speed of 10 rpm. This shows that aluminum—1.2% silicon can be deposited with essentially the same resistivity as pure aluminum ($2.7 \mu\Omega\text{-cm}$).

Data taken with and without titanium sublimation on a liquid nitrogen surface to enhance hydrogen pumping show that hydrogen does *not* play a significant role in achieving low resistivity. Nitrogen causes resistivity to increase markedly when its partial pressure is above 1×10^{-6} Torr, as shown in **Figure 3**.⁸ Oxygen also strongly affects resistivity, although no data are currently available which quantitatively relate resistivity to the oxygen content of the film. The primary oxygen bearing gas is water vapor which constitutes the major residual gas in unbaked vacuum systems. CO and CO₂ can also contribute oxygen to the plasma, but these gases normally exist at very low levels in a leak-tight system.

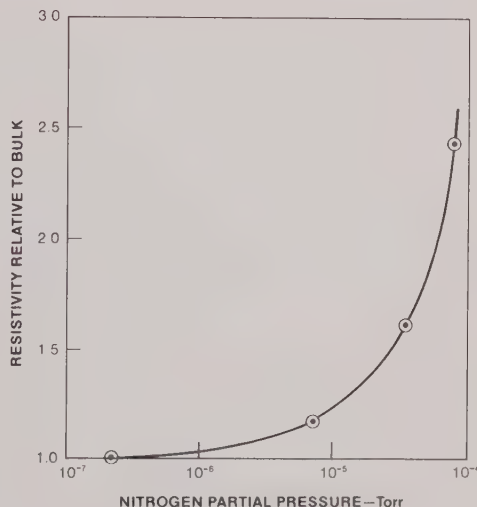


FIG. 3 Change in resistivity as a function of residual N₂ pressure.⁸

If we assume the resistivity change to be solely due to oxygen inclusion resulting from plasma dissociation of water vapor, the major gas constituent, one can see that the control of the water vapor partial pressure is of critical importance to achieving acceptable resistivity in the deposited film. The value of a loadlock and Meissner trap

becomes evident when long pumping times are to be avoided. If resistivity within 10% of bulk value is desired, the residual gases must be reduced to the low 10^{-7} Torr range.

Film Hardness

Better documented is the effect of oxygen on film hardness. **Figure 4** illustrates this effect where the hardness was measured using the Knoop method. The oxygen content was measured by Auger analysis of the film⁹. Before the hardness measurement was performed, the films were annealed at 450° to 500°C. It is seen that the hardness of the deposited film is strongly influenced even by low oxygen content.

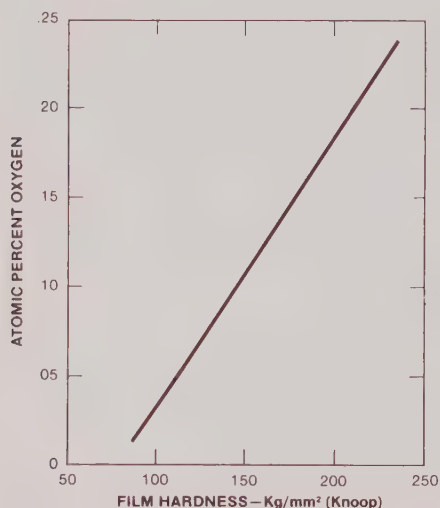


FIG. 4 Aluminum-silicon film hardness as a function of oxygen content.

The annealing step is necessary, as shown in **Figure 5**, to reduce the hardness by about 50%.

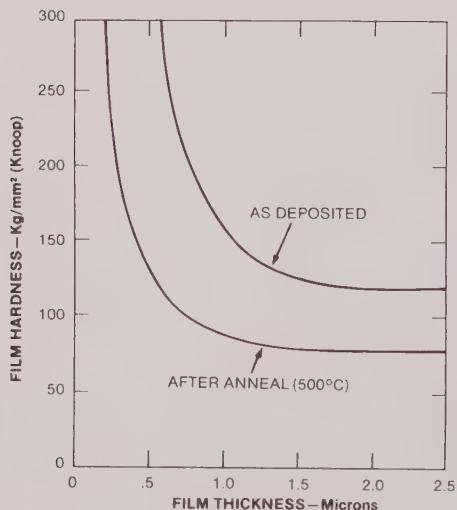


FIG. 5 Aluminum-silicon film hardness as a function of film thickness.

For film thickness less than one micron, the apparent hardness of the film is influenced by the nature of the substrate, in this case a silicon wafer. For low hardness, film thickness of at least one micron is required, with 1.5 microns being better.

The importance of film hardness has been stressed by several investigators¹⁰ because of its influence on the ability to bond to the film. Manual bonding is nearly always possible, given sufficient time, but increased use of automatic, ultrasonic bonders requires films with reproducibly low film hardness. A compilation of data from several sources leads to a curve as shown in **Figure 6**. In this figure, bonding failure does not mean failure of a bond during test but inability to achieve a bond with an automatic bonder. For reliable bonding, it is seen that a film hardness of 100 Knoop or less is required. As would be expected there is a trade-off between acceptable water vapor/oxygen levels in the system and the achievable deposition rate. The data points above a hardness of 150 in **Figure 6** are from films made at deposition rates of about 1000 Å/minute, while rates for the lower hardness films were above 4000 Å/minute. For this reason, only high deposition rate planar magnetron systems can achieve acceptably low hardness for sputtered films at this time.

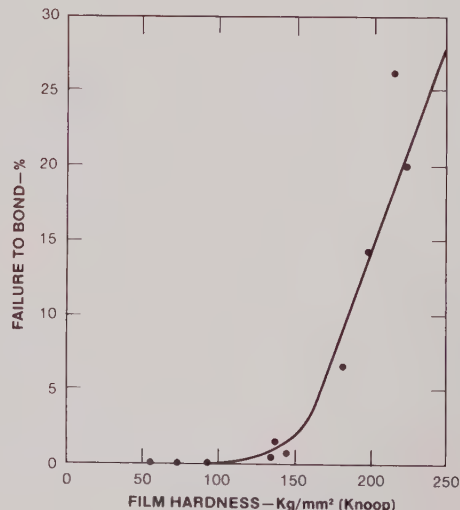


FIG. 6 Automatic bondability as a function of film hardness.

Specularity

Specularity is one of the most difficult film parameters to characterize because of the large number of variables that influence it. Specifically, the main variables influencing specularity are film temperature (determined by deposition rate and substrate motion), residual gas levels and composition, substrate cleanliness, and film thickness.

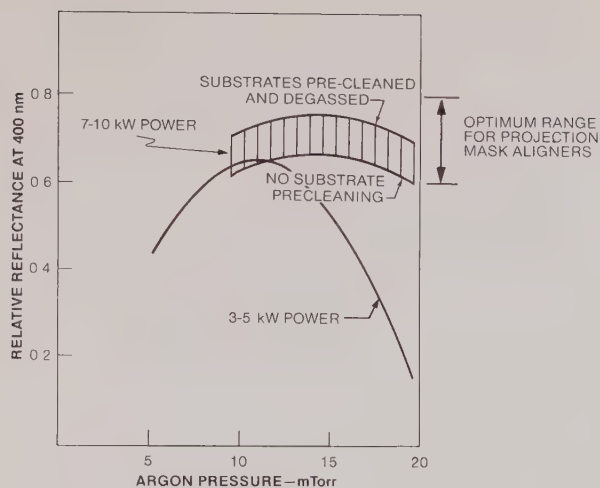


FIG. 7 Effect of power, pressure, and substrate degassing on film specularity.

Figure 7 illustrates the interrelationships of reflectance (a qualitative measure of specularity), power, and pressure. Strictly speaking, reflectance and specularity are two different properties. However, if the reflectance is measured by the specular reflection of energy from the surface, the losses represent absorption and scattering. If the reflectance is referenced to a shiny (specular) film of the material, then the reflectance measurement on a given sample is a measure of the scattering or non-specular behavior of the surface.

In the data presented here, the reflectance is measured at 400 nm (near the ultraviolet wavelengths used to expose photoresist) and is displayed *relative* to an aluminum-silicon film whose absolute reflectance at 400 nm is 93%. The improvement at higher power undoubtedly results from the lower influence gaseous contamination has at the very high deposition rate of the material. The film morphology is dictated by the deposited material and film temperature. Higher film temperature is conducive to growth of larger crystals and, hence, smoother, shinier films. The band shown for reflectance at the higher power levels shows the influence of vacuum parameters. The lower values within the band result when wafers are loaded and deposited on without proper precleaning and degassing.

If supplemental H_2 pumping is provided and outgassing of the substrates is performed during the loadlock pumpdown cycle, an improvement in reflectance of about 10% is experienced. Outgassing of the substrates within a short time period can be obtained by providing heat in the loadlock during the pumping. The temperature required depends on the time available for the outgassing.

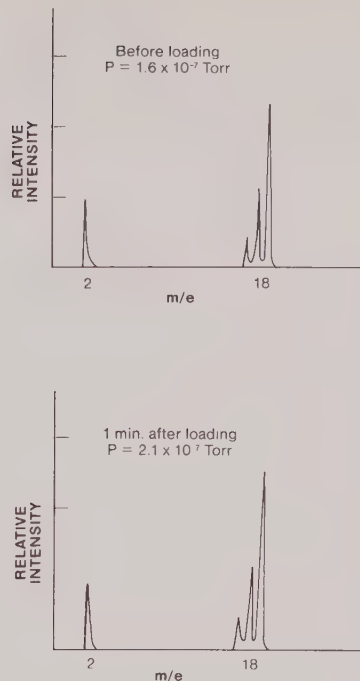


FIG. 8 Residual gas spectra before and after loading a pallet that has been preheated to 75°C for 20 min.

Figure 8 shows that outgassing at 75°C for 20 minutes results in no appreciable increase in gas load to the main vacuum chamber after loading. Increasing the temperature to 200°C reduces this outgassing period to 1.5 minutes. A Balzer's 100 l/s turbomolecular pump provided pumping into the 10^{-4} Torr range during the outgassing period. Loadlock pumping further assisted the process by reducing the level of gas influx into the main vacuum chamber when the lock valve opened to permit transfer of the substrates.

Gas composition during sputtering of aluminum-silicon is highly critical to the resultant reflectance. McLeod and Hartsough¹¹ have clearly shown the effect of nitrogen on this parameter; their results are summarized in Figure 9. A distinct haziness is seen by the eye with only a few percent degradation in reflectance and, for this reason, the nitrogen partial pressure must be kept to the order of 1×10^{-7} Torr. The work of McLeod and Hartsough also leads one to expect an effect of hydrogen on reflectance if the pressure is extended high enough. Quantitative data on actual hydrogen partial pressure are difficult to obtain during sputtering but, qualitatively, data have been obtained in our laboratory which show hydrogen to be second only to argon—as much as 25% of the gas during sputtering.

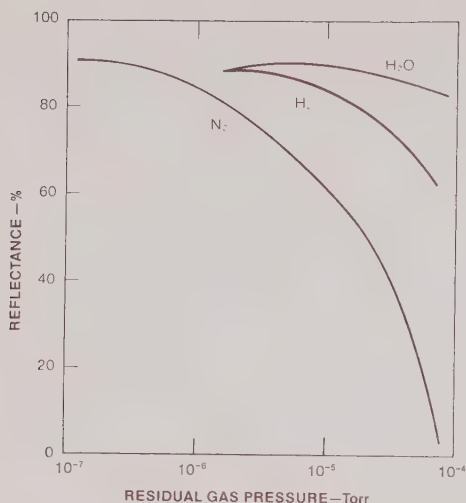


FIG. 9 Aluminum film reflectance as a function of contaminating gas pressure.

There can be several sources for the hydrogen. Most likely are dissociation of water vapor in the glow discharge and outgassing from the shutter and pallet. Hydrogen builds up unless the pumping system has high pumping speed for this gas. Turbo-molecular and throttled cryopumps do not have high hydrogen speeds. The conductance to a throttled diffusion pump is too low to take advantage of its high speed for hydrogen. Thus, we are left with several alternatives: getter pumping, specially designed cryopumps (such as the Philips K-20), or barely throttled diffusion pumps. In the last case, there is danger of excessive oil backstreaming. At this time, getter pumping appears to be the best choice.

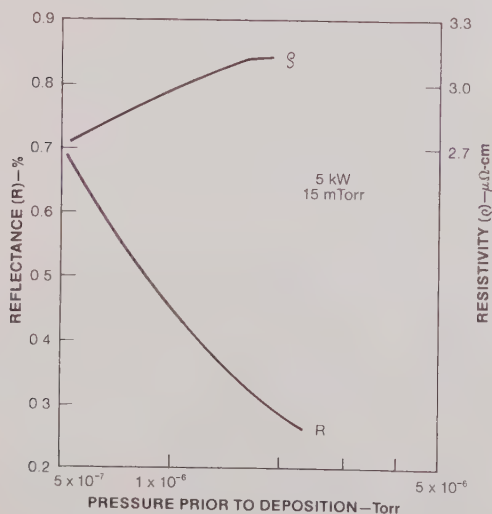


FIG. 10 Effect of base pressure on aluminum—1.2% silicon films.

A factor of two improvement in reflectance has been obtained by the simple expedient of using titanium sublimation to improve H_2 pumping. To illustrate this, several runs were made in rapid succession with the sublimator off. This allowed the partial pressure of hydrogen to build up during each run. The results, shown in **Figure 10**, reveal that an initial hydrogen partial pressure in the 10^{-6} Torr range severely degrades reflectance but causes only a slight increase in resistivity. It is estimated that the hydrogen partial pressure during deposition of these samples was well above 1×10^{-3} Torr.

The use of supplementary titanium sublimation pumping has long been advocated by Visser^{1,2} not only for reducing the hydrogen level but to assist in the clean-up of nitrogen or other adsorbed active gases. **Figure 11** shows a comparison of residual gas spectra under conditions which yield low and high reflectance films. Scanning electron micrographs are also shown depicting the hillock growth which results during aluminum sputtering in the presence of chemically active gases. The reduction in nitrogen and hydrogen clearly results in fewer hillocks and, hence, higher reflectance.

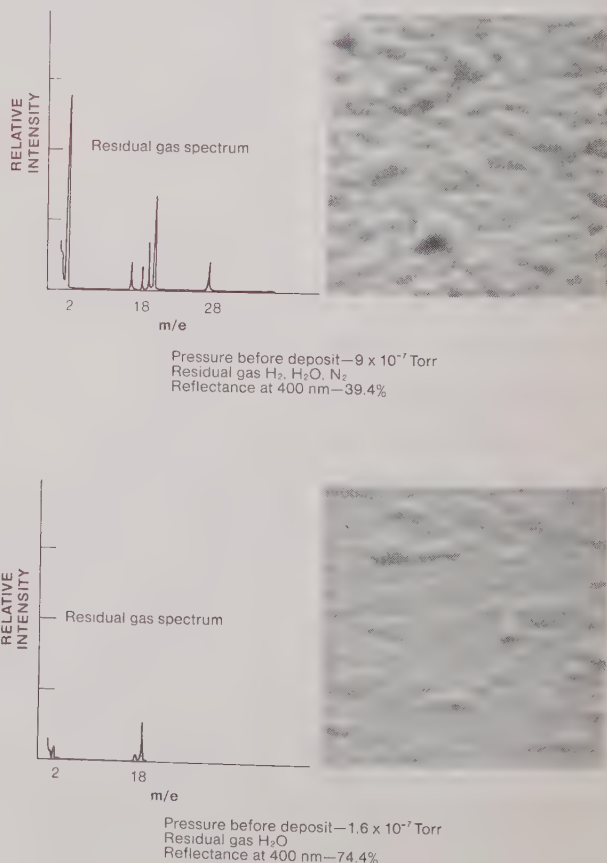


FIG. 11 Residual gas spectrum, and its effect on film hillock formation.

A third factor influencing specularly is film thickness. Under similar conditions, one obtains less specular aluminum-silicon films as the thickness increases. At the film temperatures attained during deposition, the film tends to grow in a way that permits the formation of large crystallites which grow perpendicular to the film plane. As the film grows in thickness, the beginnings of these crystallites become evident and "hillocks" form. The presence of silicon in the film tends to increase this propensity and it can be further complicated by the presence of gases that react with silicon. These include oxygen, nitrogen, and hydrogen. Thin films also have the advantage, insofar as specularly is concerned, that the deposition time is short and the film temperature is lower. **Figure 12** shows the strong dependence of specularity on thickness as measured using the ratio of the measured reflectance to the reflectance of a thin highly specular film and calling this ratio *relative reflectance*. As before, the measurements were performed at 400 nm wavelength. The line on the graph is a linear least squares fit to the data.

Little work has been done to quantitatively relate acceptable hillock density and size to film specularity (or reflectance). There are two areas in wafer processing where these properties are important: coverage by overlayers (e.g., CVD SiO_2) and photolithography. When manual mask aligning is used, a highly specular film assists the operator. Automatic aligning does not require this assist and less specular films are usable unless the scatter is so great that line definition suffers. Highly specular films are undesirable when projection mask alignment is used with negative resist. Standing waves

can be established within the resist which can cause it to lose adhesion to the underlying film. In the latter case, the best results are obtained with films having 70% to 80% reflectance.

Step Coverage

Step coverage is found to be a function of deposition rate, substrate motion, and slightly dependent on gas pressure. Submicron steps can be readily covered to better than 50% vertical to horizontal coverage ratio under almost all conditions so long as the step has no overhang. Step coverage improves as the film temperature is increased by the same mechanism that provides improved coverage on heated substrates in evaporation systems. As the temperature increases, the surface mobility of arriving aluminum atoms increases so that vertical surface coverage improves. When the film temperature increases to 300°C or higher, even steps with undercutting can be covered without "mouseholes" or cracking.

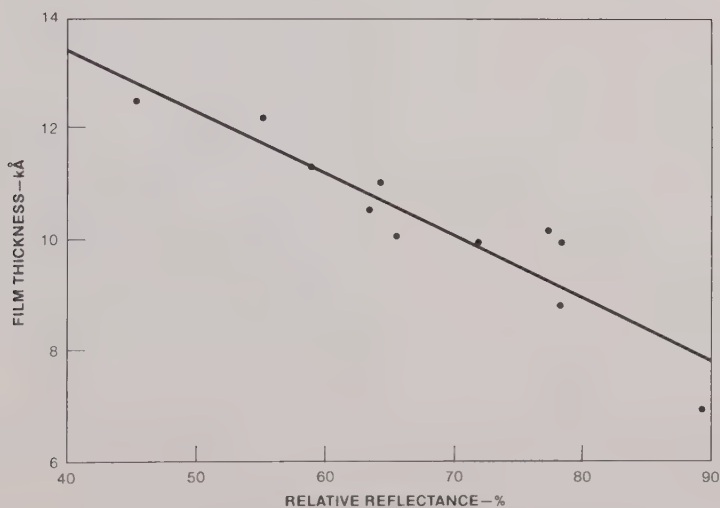


FIG. 12 Reflectance vs film thickness for aluminum—1.2% silicon.

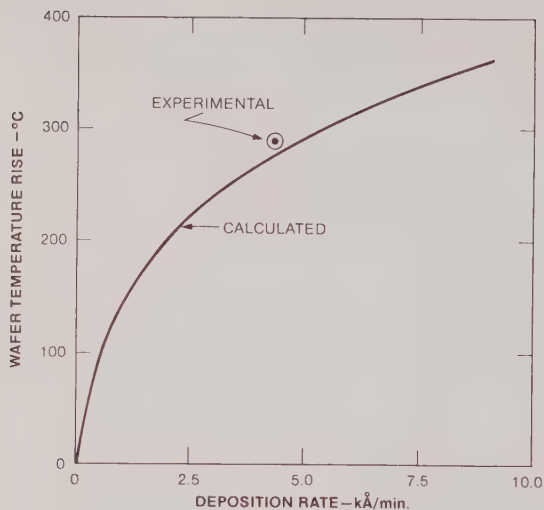


FIG. 13 Film temperature as a function of instantaneous deposition rate.

Figure 13 shows calculated film temperature vs instantaneous deposition rate based on a model which assumes that primary heating results from the heat of condensation of the aluminum and the primary cooling mechanism is radiative. Instantaneous rate is the actual deposition rate the substrate experiences while under the sputter target. **Figure 13** also shows the result of a single experiment where both the deposition rate and wafer temperature were measured. The measured rate of 4500 Å/min resulted in a temperature of about 280°C measured with Telatemp.* Agreement with the calculated curve shows the model to be reasonable. This model predicts a film temperature of 300°C with a deposition rate of about 6500 Å/min, which can be obtained with approximately 6 kilowatts into a Delta target. A full 10 kW can be applied to the target, which results in an instantaneous rate of approximately 11,000 Å/min, resulting in a film temperature of about 380°C.

It is clear that the heat of condensation alone is sufficient to achieve high film temperature. This has also been shown by Waits,¹³ who found that electron bombardment is insufficient to provide the heating. The advantage of obtaining high film temperature (for improved step coverage) by means of high deposition rate is that heaters are not required. The use of quartz lamp heaters can raise the temperature during deposition, but they also heat the rest of the system which increases out-gassing and degrades the vacuum quality which, in turn, degrades the film characteristics.

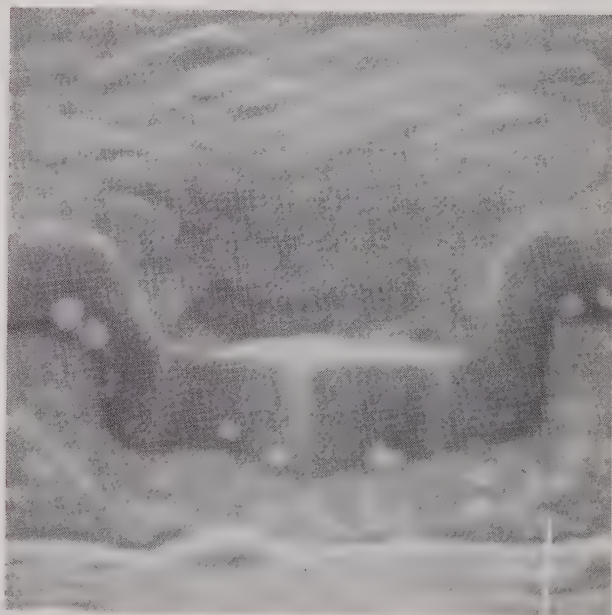
Substrate motion has been investigated with respect to its affect on step coverage. **Figure 14** shows the step coverage obtained over one micron steps during 1 pass and 60 pass deposition at an

instantaneous rate of 10,000 Å/min. The substrates were placed on the rotating table and the rotation speed adjusted so that the table made the desired



(a) one pass deposition,

14,166x



(b) 60 pass deposition.

13,750x

FIG. 14 Step coverage as a function of table rotation.

number of rotations during deposition time. The scanning electron micrographs show little change in

*Trademark of Telatemp, Fullerton, CA

step coverage with single or multipass deposition. This suggests that the important parameter is film temperature and, because thermal loss from the substrates is low, the film temperature achieved is independent of the table rotation speed and depends primarily on target power. The thermal mass of the silicon wafer is low enough that it does not seriously impede attainment of temperatures in excess of 300°C. At lower deposition rate, and, hence, lower film temperature, step coverage is still adequate but occasional cracks can occur as shown in **Figure 15**.



FIG. 15 Low deposition rate can result in film cracks.

A series of depositions was made to determine the effect of power and pressure on coverage of one micron slightly sloped steps. The pressure was varied from 5 to 20 mTorr and the target power from 3 to 10 kW. Results are summarized below:

Effect of Power and Pressure on Step Coverage

Pressure, mTorr	Step Coverage—%	
	3-5 kW	8-10 kW
5-10	50-55	51-56
15-20	55-60	56-58

The conclusion was that, for these easily covered steps, coverage is virtually unaffected by power and only slightly affected by pressure. For this reason, the pressure should be kept low and the power as high as possible in order to maximize the deposition rate.

Alloy Content and Distribution

The amount of silicon in the aluminum has already been discussed as well as reasons why high levels of silicon (greater than 1%) are not necessary. The same deposition conditions that result in low resistivity and superior step coverage are associated with high film temperature which permits excess silicon to precipitate to film surfaces and grain boundaries. If 2% silicon in aluminum is deposited at high rate, the surface concentration of silicon in the deposited film can be as high as 10% to 20%. **Figure 16** shows that a 1.2% silicon film substantially alleviates this problem with only small concentration increase occurring even when the instantaneous deposition rate exceeds 10,000 Å/minute. The use of 1% silicon would be even more desirable.

In addition to information about silicon distribution within a given film, the question can be raised about silicon segregation within the target which can result in variable results from run to run as the target erodes. This can be a problem unless the target is properly bonded and cooled during the deposition cycle. If the target temperature rises above 150°C, silicon segregation can occur as excess silicon diffuses toward the higher temperature portions of the target. If this were the case, the amount of silicon would increase in successive runs and then decrease to a level lower than the original silicon content of the target.

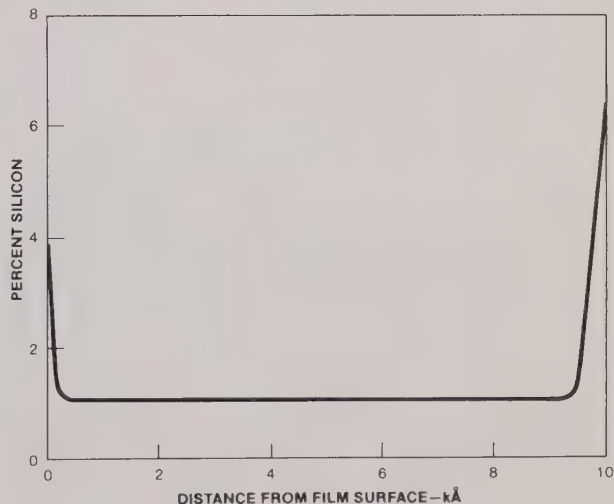


FIG. 16 Silicon profile through a one micron film with a target of 1.2% silicon concentration.

Samples were kept from each deposition cycle as a target was worn through and then analyzed

for silicon content. All samples were found to contain 1.2% silicon showing that no change in target composition was occurring. Obviously, it is important to purchase the targets from a vendor that has the technology to disperse the silicon uniformly through the target at the time of fabrication!¹⁴ The targets were metallurgically bonded to a water cooled backing plate to maintain adequate cooling.

Mobile Ion and Radiation Damage

To establish if mobile ion and radiation damage occurs as a result of deposition of aluminum-silicon from a Delta target, 1.2 micron films were deposited at 9 kW and 10 mTorr on p-type silicon wafers with a 1200 Å layer of SiO₂ and C-V plots obtained. Zaininger and Heiman¹⁵ have reviewed the C-V analytical technique extensively. In summary, the capacitor formed by a doped silicon substrate, an oxide layer and a deposited metalization layer can be utilized to determine if mobile ion and/or radiation damage results from the deposition of the metalization layer. If the substrate is of p-type silicon, application of a negative voltage to the metal layer will result in a capacitance measurement determined by the oxide thickness. As the voltage is made positive, the positive charge carriers in the substrate are neutralized by electrons attracted to the substrate-oxide interface and a depletion layer results which effectively increases the spacing in the capacitor, and the capacitance decreases. The voltage at which the transition from high to low capacitance occurs is affected by the presence of positive or negative charges, resulting from the deposition process.

In addition, charges at the interface between the substrate and the oxide result in a permanent voltage offset which is a measure of the surface state charge density at the interface. If the capacitor has a positive voltage applied and is heated to 200°-300°C, mobile ions such as sodium or potassium can move through the oxide to the semiconductor interface. When the capacitor is cooled, a capacitance-voltage measurement will show a shift in the C-V curve which is a measure of the mobile ion contamination. A negative voltage applied during a temperature cycle would also show the presence of implanted electrons or negative charges. X-rays and ultraviolet radiation result in surface states that result in a shift in the shape of the C-V plot.

Figure 17 shows a C-V plot after the deposited film was annealed at 450°C for 15 minutes in hydrogen. The positive and negative voltage stress was applied at 10 volts at a temperature of 280°-300°C. We see from this plot that there is a 0.9 volt flat band voltage resulting from semiconductor/oxide interface surface states. This compares favorably to the approximately one volt V_{FB} typically measured for evaporated aluminum films. Thus, the V_{FB} observed here is probably due to the oxide growth process. A positive voltage stress results in a 0.25 volt C-V shift and a negative voltage results in no shift.

The mobile ion concentration can be calculated from

$$N_{ss} = \frac{C_o \Delta V}{e}$$

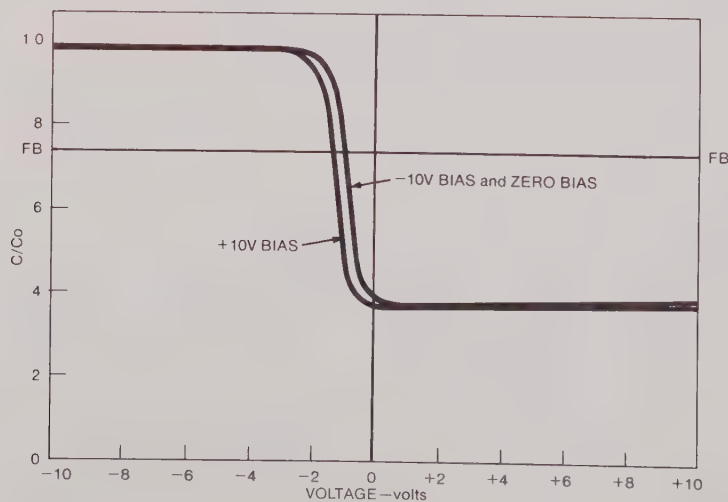


FIG. 17 The C-V plot of a film deposited at 10 kÅ/min instantaneous deposition rate.

where C_0 is the capacitance of a unit area of the capacitor resulting from the oxide thickness only. For $1200 \text{ \AA}$ of SiO_2 , C_0 is about 3×10^4 picofarads. The denominator is the electronic charge. For the curve shown in **Figure 17**, N_{ss} is 4.7×10^{10} per cm^2 . Zaininger and Heiman point out that 10^{10} to 10^{11} per cm^2 indicates a clean process. The coincidence of the negative stress curve and the "zero bias" curve show that no radiation damage occurs that cannot be annealed at 450°C in 15 minutes. The curves presented here were produced by John Asimos at Electronic Arrays, Inc. in Sunnyvale, California.

Grain Size

The film grain size is a function of the temperature the film experienced during deposition as well as the particular film alloy. The film can have alloy constituents that inhibit grain growth. For aluminum-silicon, the grain size is maximized when deposition rate is maximized. When this alloy is deposited at an intrinsic rate of greater than $8500 \text{ \AA}/\text{min}$, the mean grain size is 1-2 microns. This will increase somewhat during the anneal step in the process and can approach 3 microns. Grain size can be estimated from the micrographs in **Figure 14**.

CONCLUSIONS

Film properties of sputtered aluminum-silicon can be optimized by deposition at high rates in a clean vacuum. More specifically, the process requires that the system be capable of the following:

1. A loadlock system is essential unless very low throughput is required.
2. The loadlock must be capable of being pumped to a pressure lower than one mTorr.
3. The substrates and pallet must be degassed of water vapor prior to loading into the main chamber. This is conveniently done in the loadlock in a short time by heating to $150\text{-}200^\circ\text{C}$.
4. The main chamber must be pumped to the low 10^{-7} Torr range and have low water vapor, oxygen, and nitrogen partial pressures prior to the start of deposition.
5. The main chamber must have sufficient hydrogen pumping speed to reduce the hydrogen partial pressure to about 1×10^{-4} Torr during deposition.
6. The aluminum must be deposited at as high a rate as practical and should be at least 8500 to $9000 \text{ \AA}/\text{min}$ instantaneous rate. The $10,000$ to $11,000 \text{ \AA}/\text{min}$ provided from the Delta target at

$9\text{-}10 \text{ kW}$ produces films of excellent quality. The argon pressure should be maintained between 5 and 10 mTorr to maximize the deposition rate.

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SPUTTER DEPOSITION OF ALUMINIUM-COPPER ALLOYS

D.R. Denison and L.D. Hartsough

In an earlier report,¹ properties of aluminum-silicon films were evaluated in terms of equipment parameters that are controllable during the deposition process. It was noted that copper was one of several materials that could be added to aluminum to suppress hillock growth during deposition and thereby increase film specularly. Additionally, copper can be added to aluminum to inhibit electromigration. The current study investigates properties of aluminum-copper alloy films and controls required to optimize film characteristics for semiconductor metalization.

For the purpose of this study, a Perkin-Elmer Model 4410 sputtering system was used with high deposition rate Delta™ DC Magnetron targets capable of operating to 10 kW deposit power. The targets were obtained from Cominco-American, Spokane, Washington. Only those film properties that might be unique to aluminum-copper were investigated. Uniformity and deposition rates were found to be the same as in the aluminum-silicon study and are not repeated here. As before, some data presented here, particularly with respect to suppression of electromigration, were obtained from laboratories other than our own. These are noted and, where possible, the contributor acknowledged.

The two alloys used in this study contained 0.5 and 4 percent copper. The low copper content alloy was used for hillock suppression study and the higher copper content alloy was representative of one used for electromigration resistance. To make the hillock suppression study more comparable to the aluminum-silicon study, one percent silicon was added to the alloy containing 0.5 percent copper. Scanning electron micrographs were taken on a Hitachi S310 microscope.

Specularity

Primary system parameters affecting specularity are vacuum quality and deposition rate, as it affects film temperature. Addition of copper inhibits hillock growth but does not prevent it. (The mechanism of hillock growth is not well understood at this time. However, the same parameters that limit crystal size, such as low film temperature and additives such as copper, tend to limit hillock growth.)

Specularity measurements were made using a Coleman Model 550 spectrophotometer with normal incidence reflectance attachments. A thin (1500Å),

highly specular film of each alloy was deposited on an oxide coated silicon wafer. This film was used in the spectrophotometer reference beam. The measured sample, 10000 to 12000Å thick, was thus referenced to a highly specular film of the same material. The difference in reflectance between the sample and the reference is due primarily to surface scattering and is corrected for absorption. This reflectance is a measure of specularity.

Reflectances of the reference films for 0.5 and 4 percent copper were measured relative to an enhanced reflectance film (Mg F₂ over aluminum) with a certified reflectance of 0.98 at 500 nm. The reference films had relative reflectances at 400 nm of 98 and 98.5 percent for the 0.5 and 4 percent copper films, respectively.

Figure 1 shows specularity, measured in this manner, as a function of wavelength from 400 to 800 nm for both alloys deposited to a thickness of 11000Å in a multi-pass deposition mode (about 70 passes of the substrate under the target) at a target power of 9 kW.

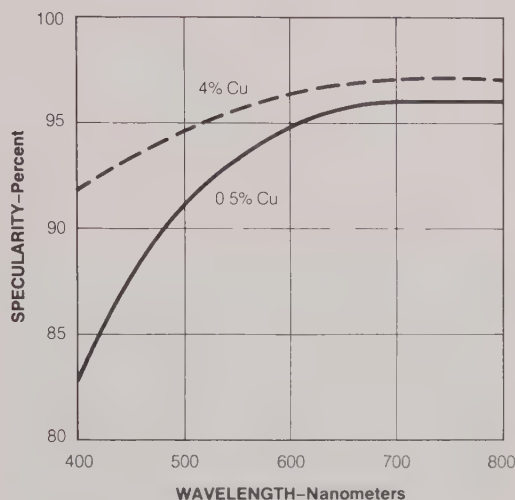


FIG. 1 Spectral behavior of specularity of 11000Å thick films of aluminum bearing 0.5% and 4% Cu.

Under the same vacuum conditions and final film thickness, specularity of films depends on the deposition rate and, thereby, the film temperature.

Figure 2 shows specularity at 400 nm wavelength as a function of instantaneous deposition rate, i.e., the actual maximum rate the substrate experiences as it passes under the target. For both alloys, film specularity

degrades as film temperature increases. This is seen from **Figures 3** and **4** to be the result of faceting of the grains in the film. Particularly in higher copper content film, segregation of the copper during film growth influences the film morphology. In these micrographs, the viewing angle is 60 degrees from normal to enhance the topography. When the films are annealed in N_2 at $500^\circ C$ for $\frac{1}{2}$ -hour, there is about 5 percent loss in specularity. However, this is due to increased faceting and is *not* because of hillock growth. Both alloys show excellent resistance to hillock growth during the anneal cycle.

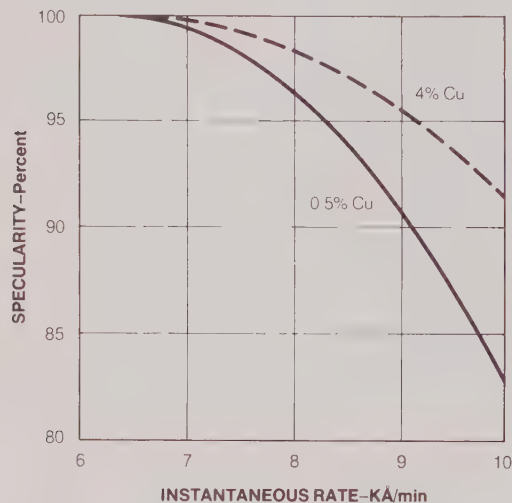


FIG. 2 Effect of deposition rate on specularity at 400 nm of 11000Å thick films of aluminum bearing 0.5% and 4% Cu.

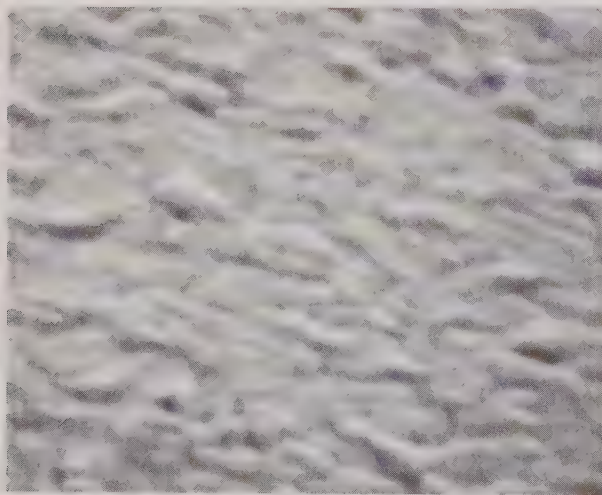


FIG. 3 Faceting of crystal surfaces in an Al/0.5% Cu film at 20000x magnification. Thickness is 11000Å.

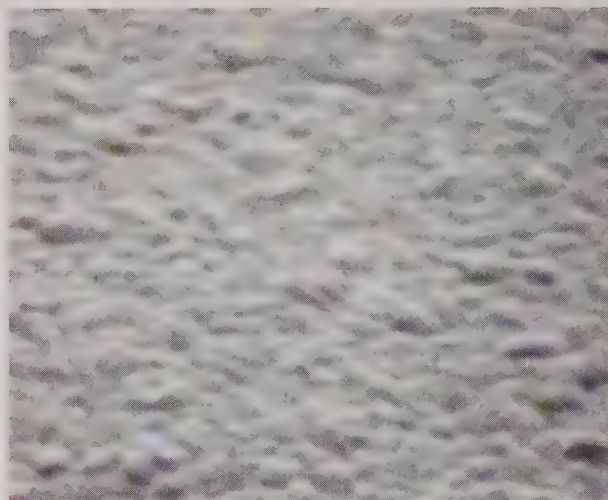


FIG. 4 Surface features of Al/4% Cu at 20000x magnification. Thickness is 11000Å.

As in the case of aluminum-silicon, there is a thickness dependence to the specularity. As the film becomes thicker, specularity degrades. **Figure 5** shows this dependence for both 0.5 and 4 percent aluminum-copper alloys deposited at the high rate of 10000Å/min instantaneous rate. Specularity is measured at 400 nm wavelength because of the importance of the near ultraviolet in photolithography.

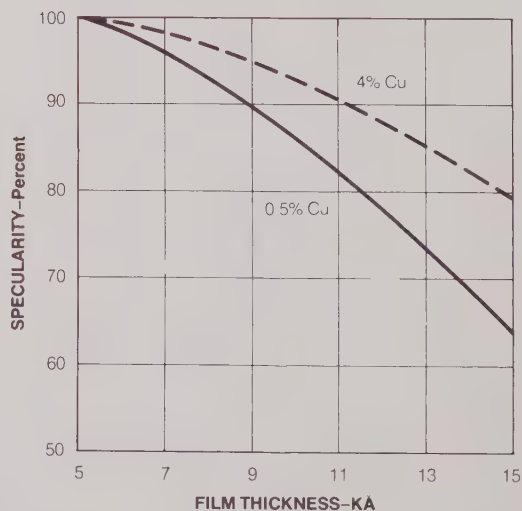


FIG. 5 Effect of film thickness on specularity at 400 nm of copper bearing aluminum films.

Comparison of **Figures 5** and **2** reveals that similar, higher specularity vs. thickness curves can be obtained with lower deposition rate. A trade-off between

specularity and substrate throughput can be made to obtain the optimum film quality for a given process requirement.

When aluminum-copper is deposited at high rates in the single pass mode, film morphology changes from leading to trailing edge. The substrate enters the deposit region at relatively low temperature and as deposition takes place, substrate temperature rises and subsequent "zones" across the substrate begin deposition at higher and higher temperatures. A four percent copper alloy film deposited in a single pass at 10000Å/min gives specularity at 400 nm as a function of position across the wafer. This is shown in **Figure 6**. The aluminum-copper phase diagram² shows a eutectic at 17.3 percent copper and a melting point of 548°C. This composition can be reached when copper in the film segregates. The trailing edge of the wafer had a melted appearance, which may be a result of film temperature exceeding 500°C. One solution is to decrease the deposition rate and thereby decrease the maximum temperature achieved during deposition. This, however, has an adverse impact on substrate throughput because of the longer deposit time. A more viable solution is to increase the number of substrate table rotations.

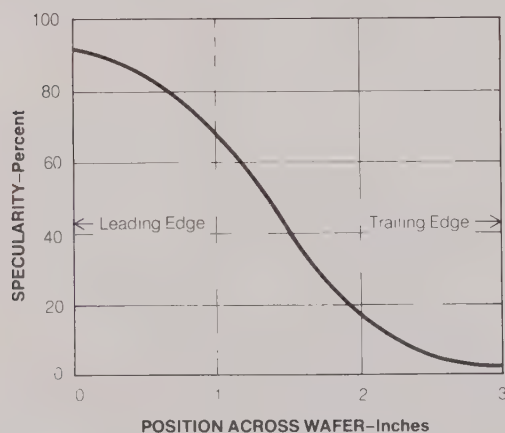


FIG. 6 Specularity profile at 400 nm across an oxidized silicon wafer coated with Al/4% Cu in a single pass deposition with a rate of 10000Å/min.

Figure 7 plots specularity across the substrate, showing that aluminum-4% copper can be deposited at high rate in the multi-pass mode without film degradation, and that substrate temperature increases uniformly with no variation in specularity. For about five-sixths of the table rotation time, the substrate is out of the deposition area. This is sufficient to radiate enough energy that the maximum temperature does not cause film melting, but still results in good step coverage.

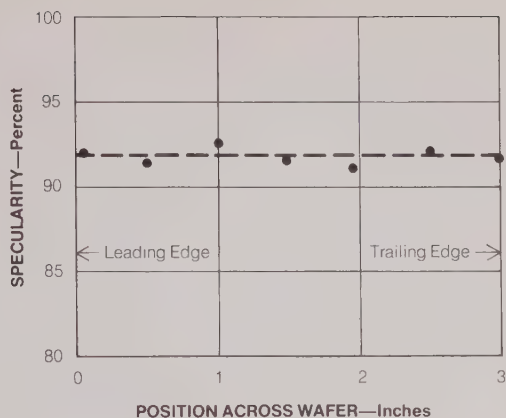


FIG. 7 Specularity at 400 nm is uniform across an Al/4% Cu film deposited in a multi-pass mode.

It is important, however, to maintain scrupulously clean vacuum conditions in this mode so the film is not contaminated. The 4410 system used in this investigation was equipped with a closed-cycle helium gas cryopump and liquid nitrogen Meissner trap to maintain such clean conditions. Film resistivity was measured to be 2.9 ± 0.1 microhm-cm which demonstrates that films may be deposited in the multi-pass mode with negligible contamination. Learn³ has shown that aluminum-4% copper should have bulk resistivity in the range of 2.82 to 3.12 microhm-cm.

For comparison, Ian Bell⁴ of National Semiconductor Corp. provided evaporated films of 4% copper alloy as deposited from a single source and after a 475°C anneal for ½-hour in N₂. As deposited, specularity was 36.5 percent at 400 nm and 26 percent after anneal. A scanning electron micrograph showed that loss of specularity in the deposited film was due to an irregular surface of fairly large grain size. No hillocks were observed. After anneal, further degradation in specularity resulted from growth of hillocks whose density was estimated to be on the order of 10⁶ per cm².

Electromigration

The phenomenon of electromigration was first observed by Johnson⁵ and studied by Schmidt⁶ and Langmuir⁷ during the study of a so-called "dc etch" on single crystal tungsten filaments heated in vacuum. This phenomenon is a mass transport of metal atoms when a direct electric current is passed through the metal. Penney⁸ investigated electromigration in aluminum and found that the atoms migrate in the direction of electron flow. Heumann and Meiners⁹ related the electromigration to aluminum grain size which suggests grain boundary diffusion as the mechanism. Large grains exhibit less migration than small grains. One would expect, therefore, that the addition of a material to the aluminum that inhibits grain-boundary diffusion would reduce

electromigration. Copper has been empirically found to be such a material.

Accelerated life testing at elevated temperature and increased current density is used to evaluate the efficacy of the alloy used. Nitta¹⁰ has investigated the mean time to failure of aluminum-copper alloys as a function of copper content. The failure distribution is shown in **Figure 8** with mean time being the point at which fifty percent of the traces have failed. These data indicate that more than 4 percent copper is probably unnecessary, although Nitta indicates some additional improvement is found with as high as 10 percent copper. Nitta's failure data for small grain and large grain aluminum-silicon are given for comparison.

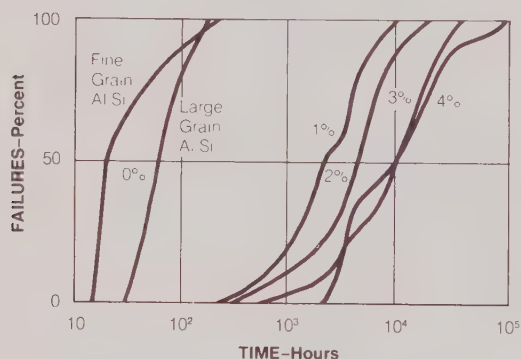


FIG. 8 Dependence of 9 micron trace failure on the film copper content. Temperature is 150°C and current density 1×10^6 A/cm².

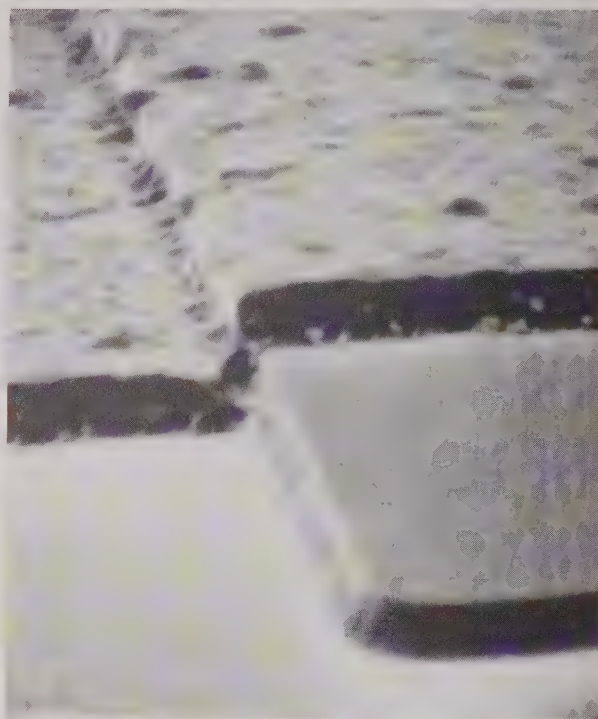
Step Coverage

As in the case of aluminum-silicon, step coverage is substantially a function of film temperature. A high film temperature can be obtained without degradation of vacuum quality by achieving very high rate deposition.

Figure 9 shows step coverage for the 0.5 percent copper alloy for single and multi-pass modes of deposition. In the multi-pass mode, the substrate passes under the target approximately 70 times. There is no substantial difference in step coverage between the two modes. **Figure 10** shows step coverage for the 4 percent alloy in the multi-pass mode. For single pass, the character of the film changed dramatically across the substrate. The instantaneous rate seen by the substrate was about 10000 Å/min.

Figure 11 shows coverage at the leading edge, the center of a 3-inch wafer, and the trailing edge. Near the trailing edge of the wafer, step coverage cannot be measured because of apparent melting of the film over the oxide step. The single pass mode can be used if the deposition rate is limited to about 7000 Å/min to prevent excessive film heating. Throughput of a production sputtering system would be adversely affected by this

lowered deposition rate; therefore, multi-pass mode would be preferred for this alloy.



(a) Single Pass



(b) Multi-pass

FIG. 9 Step coverage of Al/0.5% Cu/1% Si films 10000 Å thick deposited in (a) single pass and (b) multi-pass modes.

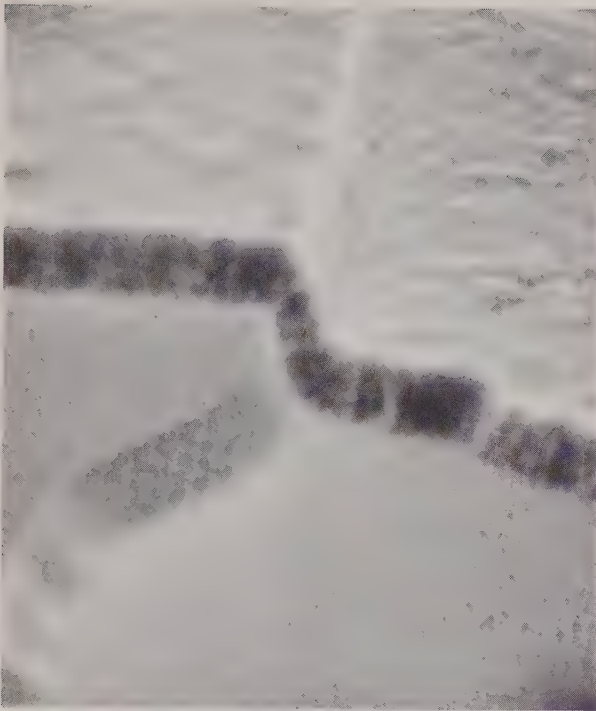
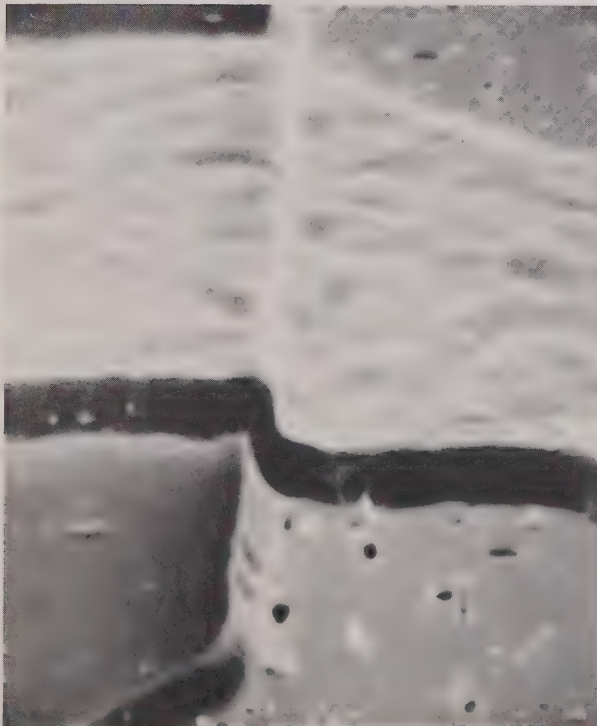


FIG. 10. Step coverage of 10000Å thick Al/4% Cu deposited in the multi-pass mode at 10000Å/min instantaneous rate.



(b) Wafer Center



(a) Leading Edge



(c) Trailing Edge

FIG. 11 Film appearance and step coverage of Al/4% Cu deposited at 10000Å/min in the single pass mode. The leading edge (a), wafer center (b), and trailing edge (c) show the effect of progressively higher film temperature.

Grain-Size

Grain size is a function of film temperature during deposition and as such is dependent on deposition rate. In the multi-pass mode, maximum film temperature is limited by radiative cooling while the substrate is out of the deposition region. Approximately one-sixth of the substrate carrier experiences deposition at any one time and, thus, during five-sixths of the table rotation time, the wafer cools somewhat by radiation. In the single pass mode, this cooling mechanism is not present and wafer temperature is higher.

The alloy with 0.5% copper deposited at 9 kW target power (about 10000Å/min deposition rate) had about 0.3 to 0.5 micron grain size for both multi-pass and single pass deposition modes. Annealing at 500°C in N₂ for ½-hour showed no change in grain size for the multi-pass deposited film, but the single pass deposited film grains increased to 0.8 to 1 micron size.

The 4% copper alloy has already been shown to differ substantially between the multi-pass and single pass modes at high deposition rate. This is further accentuated in grain size. The multi-pass deposited films have grain size of 0.3 to 0.5 micron. The leading edge of single pass films had a grain size of 0.5 to 1 micron which increased at wafer center to 10 to 20 microns, while the trailing edge showed major disruption of the film structure.

For comparison, evaporated films provided by Ian Bell⁴ showed fairly regularly shaped grains about 1 micron across as deposited. After anneal, the grains were about the same size or smaller and much more irregular in shape.

Alloy Composition

The phase diagram cited earlier², shows solubility of copper in aluminum to be less than 0.2 weight percent at room temperature in equilibrium with a theta phase having a composition approximating CuAl₂. At 500°C, solubility is 4.08 weight percent.

Figure 12 shows the composition profile for a film of 0.5 percent copper — 1 percent silicon deposited at an instantaneous rate of 10000Å/min. The profile was obtained with a Physical Electronics Model 545 Scanning Auger Microprobe. The copper and silicon are at a concentration near the detection limit in the presence of aluminum as the major constituent. The important aspect of this figure is that there is no evidence of segregation of either of the minor constituents. Copper remains evenly distributed in the film and, at 1 percent, the silicon shows no diffusion toward the film surfaces.

When the 4 percent alloy is deposited (multi-pass) at high rate, the composition profile obtained is that shown in **Figure 13**. At the film temperature achieved during high rate deposition, copper begins to precipitate near the substrate surface and as the film grows, the driving force is to build a theta phase layer. There is insufficient copper in the film to generate a theta phase layer greater than about 500Å thick which is

inconsistent with the profile shown in **Figure 13**. The possibility must be considered that theta phase aluminum-copper is distributed through the film, perhaps in the grain boundaries, so that the average composition appears as in the profile. It must be noted that the Model 545 Auger Microprobe has an analyzing beam about 10 microns in diameter. With a grain size of 0.3 to 0.5 micron, the profile shows copper concentration averaged over several grains. If the average grain is 0.4 micron in diameter, the grain boundary would need to contain a layer of theta phase composition only about 35Å thick with the grain interior devoid of copper to appear as an average composition of 11 weight percent (5 at. percent).

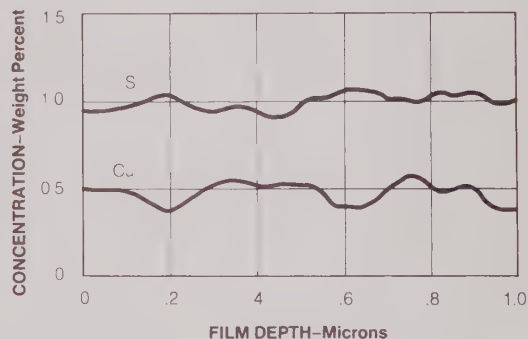


FIG. 12 Copper and silicon distribution in an Al/0.5% Cu/1% Si film as deposited.

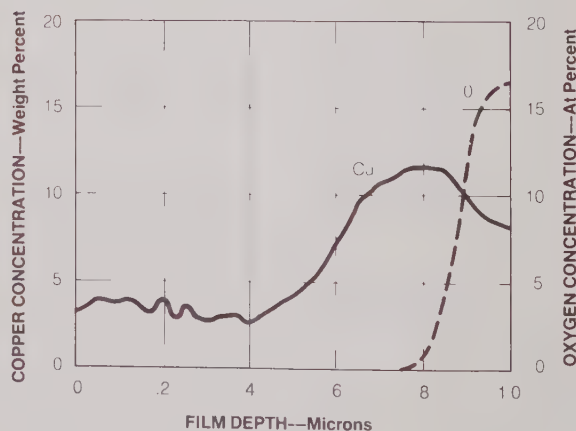


FIG. 13 Copper and oxygen distribution in film deposited from an Al/4% Cu target showing copper segregation and evidence of Al reaction with the substrate oxide.

When the film is annealed at 500°C, copper tends to redistribute since the solubility increases to 4.08 weight percent. As shown in **Figure 14**, this redistribution occurs very slowly, implying that even at 500°C, the kinetics are only slightly tipped against theta phase

formation. This is in contrast to the evaporated film whose profile before and after a ½-hour anneal is shown in **Figure 15**. In this case, a short anneal at 475°C was sufficient to redistribute the copper. The profile as deposited shows a similar enrichment of the copper content near the film-substrate interface to that in the sputtered film. Without more detailed analysis, one can only speculate on the difference in copper redistribution mechanism in the evaporated and sputtered films. This difference is also manifest in hillock growth, with the evaporated film showing substantial hillock growth during anneal and the sputtered film showing none. Bell⁴ also reports that the sputtered film is more resistant to corrosion.

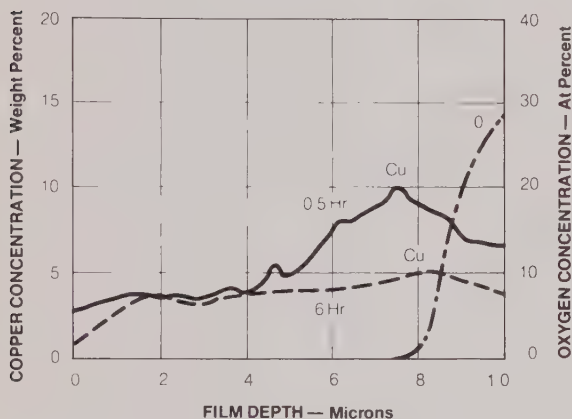


FIG. 14 Copper distribution in the film of Fig. 13 after ½-hour and 6 hours anneal at 500°C in N₂.

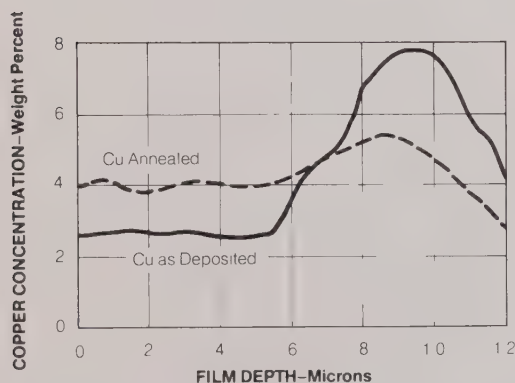


FIG. 15 Copper distribution in a 4% Cu evaporated film before and after annealing at 500°C for ½-hour in N₂.

Both **Figures 13** and **14** show the presence of reaction between the depositing aluminum and the underlying silicon dioxide. The heat of formation of aluminum oxide is approximately twice that of silicon dioxide so if the deposition temperature is high enough

to provide the reaction activation energy, this reaction can take place. During the ½-hour anneal at 500°C, the reaction continued to supply oxygen to the aluminum layer but the depth of the oxide layer did not change. Additional heating caused no further change. The thickness of this oxide layer stabilizes at a few hundred angstroms and no effect on film resistivity is observed.

Results reported here are at variance with those reported by Learn³ for films deposited by flash evaporation and by Mader and Herd¹¹ for films deposited by r.f. sputtering at low rate on cleaved KCl substrates to give thin, single crystal films. In both of these references, the preferential sites for nucleation of theta phase aluminum-copper is the free surface of the film, in contrast to the substrate interface found in using high rate sputter deposition. There is need for more work to fully understand the mechanisms for differences in copper segregation in evaporated and high rate sputtered films.

Mobile Ion and Radiation Damage

In the report on aluminum-silicon deposition,¹ a C-V plot was presented which showed that no radiation damage was caused by the DeltaTM magnetron cathode that was unannealable at 450°C in 20 minutes. Mobile ion concentration also was shown to be within acceptable limits. The C-V plot in **Figure 16** was obtained by Hanson¹² of Fairchild Semiconductor Division using a deposit of 0.5% copper alloy. After anneal at 475°C for 30 minutes both positive and negative voltage stressing at 300°C for 2 minutes gave plots that are indistinguishable from the zero bias plot. This repeats the result on radiation damage seen in the former report, but also shows that total process cleanliness can eliminate the shift resulting from mobile ion contamination. In the sputtering process, vacuum system cleanliness and maximum target purity are essential. Oxide growth must also be totally free from contamination. The results seen here show that this can actually be accomplished.

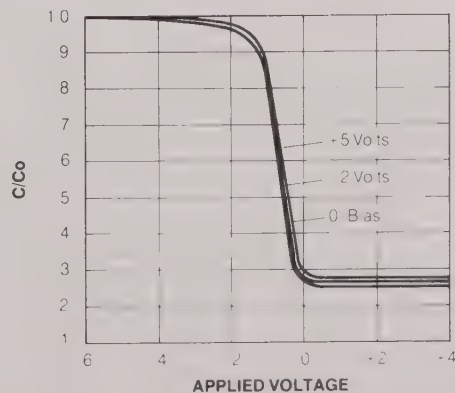


FIG. 16 C-V plot of Al/0.5% Cu/1% Si deposited on a p-type silicon wafer. No evidence of mobile ion or unannealable radiation damage is seen.

Film Hardness

The earlier report on aluminum-silicon deposition demonstrated that film hardness has a direct bearing on successful automatic, ultrasonic bonding. The data presented here are preliminary measurements using a Leitz microhardness tester at 5 g load, but demonstrate the effect of copper on film hardness and suggest a means for improving bonding to these films.

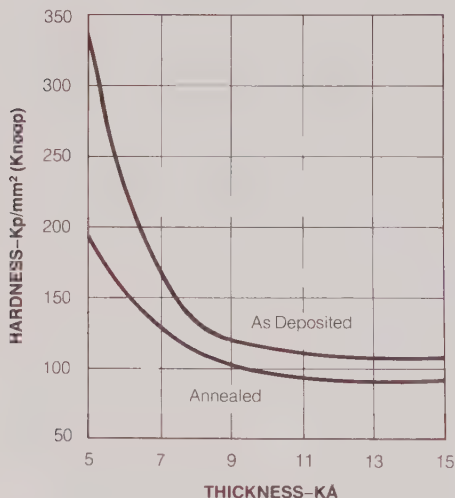


FIG. 17 Film hardness vs. film thickness for Al/0.5% Cu/1% Si as deposited and after 500°C ½-hour anneal.

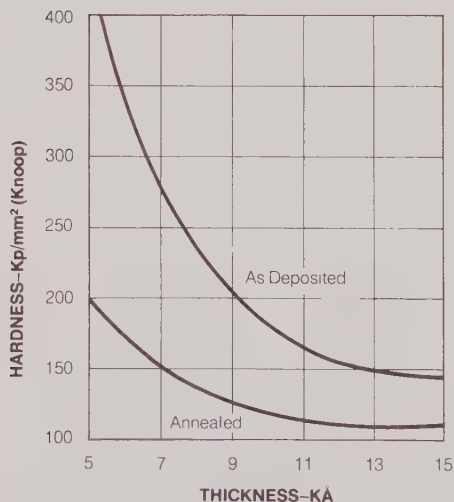


FIG. 18 Film hardness vs. film thickness for Al/4% Cu as deposited and after 500°C ½-hour anneal.

Figure 17 shows film hardness of Al/0.5% Cu/1% Si as a function of film thickness. Within measurement error, hardness is the same as aluminum-silicon without copper. The addition of only 0.5 percent copper does little to the hardness of the film. **Figure 18** shows the same data for aluminum with 4 percent copper. A substantial increase in hardness is evident. Even after anneal at 500°C for ½-hour in nitrogen, the hardness is greater than 110 on the Knoop scale. This would imply, from the previous work, that some bonding problems could result to a small extent. In high volume production, even a small yield loss can be important. Also, with VLSI, a 1 percent bond failure rate on a 40 lead device can result in catastrophic yield losses. The flexibility of a sputtering system can be put to good use by overcoating the aluminum-copper with a layer of pure aluminum to reduce the effective hardness for high bond reliability.

Summary

Whether copper is added to the metalization film to obtain highly specular films or to inhibit electromigration, high quality films can be obtained by observing the following:

1. Deposition should take place in a load locked system with a base pressure in the low 10^{-7} Torr range to minimize residual gas contamination of the film.
2. Deposition should occur at as high a rate as possible without melting the film to minimize film resistivity and film hardness, thus maintaining good bondability.
3. High rate, multi-pass deposition is preferred to maximize uniformity of film characteristics across the substrates.

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SPUTTERING OF Ti:W FILMS USING RF SUBSTRATE BIAS*

L. D. Hartsough

The desired resistivity for both dc magnetron- and rf-sputtered Ti:W films is in the 60–90 micro-ohm-cm range. The question was asked whether biasing the rf substrate could be used as a tool to help keep resistivity within the desired range.

Ti:W films were deposited using rf substrate bias and both dc magnetron and rf diode sputtering technique. In both cases, the rf induced dc self bias potential on the substrate carrier was varied from zero to –300 volts. Resistivity of the Ti:W film could be varied over a 2:1 range by means of substrate bias. The rf sputtered films had higher resistivities than did the dc sputtered ones.

Auger analysis showed large decreases in Ti content as bias voltage was increased. An effect of target power was also found. Oxygen content of the rf sputtered films also decreased with increasing bias, but in the dc sputtered films it showed no correlation with bias. Calculated values of Ti concentration in the films with no bias were lower than in the target by a factor of two, indicating a systematic error in Ti content calculated from the sensitivity factors used. This is thought to be due to preferential Ti sputtering during the AES film profiling, rather than errors in sensitivity factors.

Resistivity of the Ti:W films showed a strong, linear correlation with Ti content in the dc sputtered films. The situation is less clear with the rf sputtered films, which were more contaminated with oxygen.

Use of Ti:W Films

A titanium-tungsten mixture, in the ratio 10:90 by weight (30:70 atomic), has been used in interconnect metallizations as an adhesion and diffusion barrier layer. This mixture provides good corrosion resistance compared to other refractory metals.¹ A typical metallization for shallow junction devices consists of PtSi, for good contact and/or Schottky characteristics, Ti:W, and Al or Au as the conductor.^{2,3,4} The Ti:W is universally deposited by sputtering.

Recently, the semiconductor industry has started using Ti:W films for fuses in memory devices (PROMs). The requirement here is a certain resistivity, typically in the 70–90 micro-ohm-cm range. Devices are often designed around a resistivity value obtained experimentally in a particular piece of equipment, with a particular target, sputtered by a particular process. This can present problems when the process is transferred from development to production.

Ti:W targets are made from hot pressed powders and can produce films which vary, from target-to-target, and even within a target. This is because density, interstitial contaminants (O, N) and composition can vary. Film properties also depend on process parameters such as deposition rate, residual gas levels, and argon pressure. Thus, a production coating system may not give the film resistivity for which the device was designed.

There is, however, a process parameter by which resistivity of refractory metal films can be controlled. This parameter is rf substrate bias. It has been known for years that the resistivity of pure refractory metal films decreases as bias voltage is increased.⁵ The decrease in resistivity for these films is due to the reduction in concentration of interstitial impurities, such as oxygen, by preferential resputtering.^{6,7}

The purpose of this study was to determine how much the resistivity of Ti:W films could be varied by means of substrate bias and to see if the gas content was responsible for the variation.

The Deposition Process

Most of the films were deposited by dc magnetron sputtering, with rf substrate bias, in a Perkin-Elmer Model 4400 sputtering system, which has a 23-inch (584 mm) diameter rotating annular substrate pallet. The system has a load lock and is pumped by a closed cycle helium cryopump and a Meissner trap. The 8-inch (203 mm) diameter target was powered at 2kW and the rf-induced dc substrate bias voltage was varied from zero to –300 volts. Argon pressure was varied between 5 and 15 m Torr ($6.7 \times 10^{-1} - 2$ Pa) and film thickness from 100 to 300 nm. Substrates were oxidized and unoxidized silicon wafers. Several runs were made with an rf source in a Perkin-Elmer Model 2400-8L sputtering system. In this system the stationary substrate carrier (the biased electrode) is 8 inches in diameter, the same size as the target. This system is a batch-type and is pumped by an LN₂-trapped turbomolecular pump.

*Based on a paper presented at the International Conference on Metallurgical Coatings, San Diego, 23–27 April 1979

Thickness measurements were made with a Beta-Scope,⁸ beta particle back-scatter instrument. Sheet resistance was measured with a four point probe. Auger analysis was performed at Physical Electronics Industries on a Model 545 scanning Auger system.

For analysis of the AES spectra and conversion to atomic percentages, the following sensitivity factors were used: For Ti, 0.34; for W, 0.08 and O, 0.40. The Ti:W ratio was calculated based on metallic constituents only (Ti and W), and the oxygen:metal ratio was based on all measured components (Ti, W, and O).

Results for dc Sputtered Films

The variation of rf bias power with pressure turned out to be the rate-determining factor for these bias-sputtered films. This was found to be true even though deposition rate is not a strong function of argon pressure when dealing with zero-bias, dc magnetron films.

Figure 1 shows that the deposition rate dropped sharply between 300 and 400 watts of substrate power. Because the dc power to the target was held constant at two kW during all runs, the entire drop in rate can be attributed to resputtering. Although there was a slight decrease in rate at the lower bias powers, a threshold of 100–150 volts was apparently required for substantial resputtering to occur. For each series of runs made under similar conditions a resputtering rate was calculated as the difference between zero bias rate and rate at a given bias, with other conditions being equal.

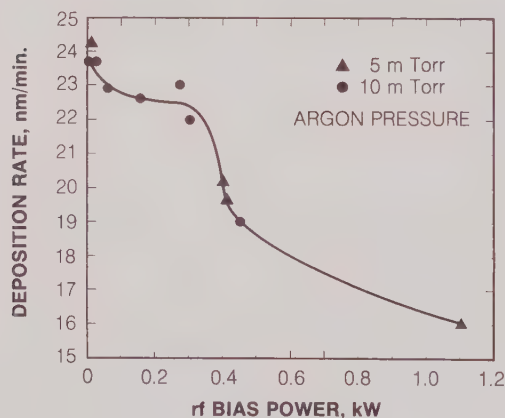


FIG. 1 Net deposition rate vs rf substrate bias power for dc magnetron sputtered Ti:W films.

It might be expected that resistivity would correlate strongly with the resputtering rate, but this was not found to be the case. (The correlation coefficient was $r = 0.69$.) However, for samples made under similar conditions, resistivity did correlate well with bias power, as shown in **Figure 2**.

Sputter etch cleaning of the substrates seemed to affect the resistivity of the films. When it was performed there was about a 10% drop in resistivity, with a small additional decrease if the pressure was returned to the 10^{-7} Torr range before deposition.

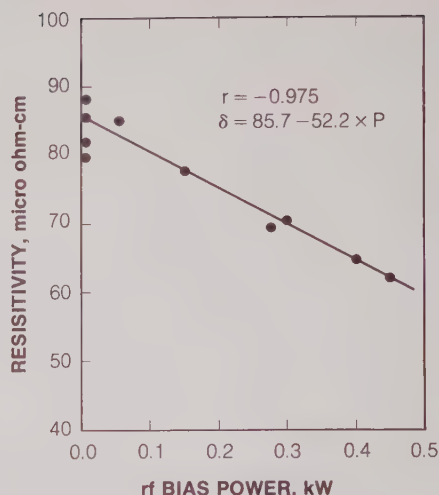


FIG. 2 Resistivity vs rf substrate bias power for dc magnetron sputtered Ti:W films.

Composition vs. Bias

AES revealed that the Ti:W ratio decreased markedly with increased bias, and was monotonic within a given set of runs, but the ratio was different from set to set. This may be due to several factors. Although all runs were made from the same target, several different dc and rf power supplies were used during the year over which samples were made. Another explanation is that the target itself may have been inhomogeneous. Also, even though the samples were measured on the same Auger system, analysis conditions may have varied slightly from time-to-time. It was found that the Ti 418 ev signal varied with bombarding ion energy and was also affected by adsorbed oxygen, whereas the W 1736 ev signal was unaffected by either of these factors.

The large decrease in Ti concentration with bias is attributed to preferential resputtering of the Ti relative to W during deposition. This would be unexpected if one used the sputter yields for pure Ti and W (0.65 and 0.6, respectively, at 500 ev⁹).

However, when the large mass difference between Ti and W is considered, preferential resputtering of the Ti becomes plausible.¹⁰ In a direct two-particle collision an Argon ion imparts 99% of its energy to a titanium atom, whereas only 60% of its energy is transferred to a tungsten atom. If a knocked-on Ti atom collides with a W or a Ti atom it can be backscattered at any angle up to 180°, but a W atom colliding with a Ti atom can be deflected by at most 15° and would likely have to undergo several collisions before being ejected from the surface. Thus, in a Ti:W mixture, the Ti atoms receive more energy and are more easily backscattered. Because the surface of the film is constantly being renewed, there is no time for formation of a steady state, altered surface layer.

Resistivity vs. Composition

The correlation between Ti:W ratio and resistivity is shown in **Figure 3**, for data from three different series of depositions. Within each set of data the linear relationship between resistivity and titanium content is almost perfect. The straight line is a least squares fit to all the data points. For a Ti:W atomic ratio equal to that nominally in the target, the value would be 0.43, whereas measured ratios were about 0.15 for zero bias films. The discrepancy is undoubtedly largely due to preferential Ti sputtering during AES. Further work is being done to calibrate Auger results to the actual film composition. However, it is likely that the relative compositions are reasonably accurate, as the following discussion indicates.

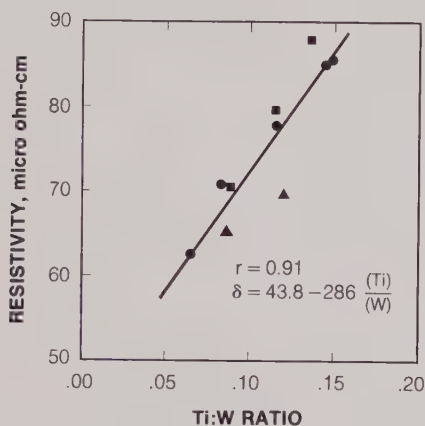


FIG. 3 Resistivity vs Ti:W ratio calculated from AES Profiles of dc magnetron sputtered Ti:W films with rf substrate bias. Data are from three series of runs and are differentiated by shape of the plotted points. The line is a least-squares fit to all the data points.

Analysis of Auger Data

Ghate, et al³, show a depth profile in which the Ti:W ratio is quite similar to those observed for our films. Their films were rf sputtered with no substrate bias. Resistivity of their films was 90 ± 10 micro ohm-cm, and thickness was 150 nm. Thus, our AES data are in agreement with previous work on similar films. Nowicki, et al⁴, analyzed their rf sputtered Ti:W films (150 nm thick, 80–100 micro ohm-cm) using helium ion backscattering spectrometry (HIBS). The Ti content was 34.2 at. % (ratio to W) at zero substrate bias and dropped to 31.1 at. % at –50 volts bias. These authors also show an Auger depth profile. The Ti content calculated from the peak-to-peak heights, using the sensitivities given earlier, is 17.5%.

If our data are multiplied by the 34.2:17.5 ratio implied by these data, the Ti content of our films at zero bias is nearly equal to that nominally in the target. Further, it appears plausible that relative sputtering yields of Ti and W in the film would not change much with film composition. If so,

relative measured AES concentrations will not change when corrected for preferential sputtering as shown next.

Assume that the yields Y_{Ti} and Y_W are constant
In a film with Composition Ti_1 and W_1 the Ti:W ratio in the sputtered flux, at steady state, will be equal to the bulk concentration of the film:

$$\frac{Ti_1}{W_1} = \frac{Y_{Ti}Ti_1'}{Y_WW_1'}$$

where the primes denote composition of the film in the altered surface layer from which sputtering occurs
Likewise, in another film of composition Ti_2 and W_2 ,

$$\frac{Ti_2}{W_2} = \frac{Y_{Ti}Ti_2'}{Y_WW_2'}$$

The ratio of surface compositions of the two films is then

$$\frac{Ti_1'/W_1'}{Ti_2'/W_2'} = \frac{(Y_W/Y_{Ti})(Ti_1/W_1)}{(Y_W/Y_{Ti})(Ti_2/W_2)}$$

Since the yields cancel, the relative compositions of the surface layers are equal to the relative compositions of the films. Thus, the strong correlation between Ti:W ratio and resistivity should hold even after the Ti content is correctly established.

Oxygen Content

Oxygen to metal ratios (O:M) were found to be between 0.01 and 0.05 for the dc magnetron sputtered Ti:W films. There was essentially no correlation ($r = 0.017$) between O:M and bias level, unlike the rf sputtered films. It is probable that most of the variation in oxygen peak-to-peak heights in the AES signal was due to random fluctuations, although there was definitely an O peak (503 ev) in all spectra. The fact that data were taken in several sessions could again have affected the results.

Target Power

It has been reported¹¹ that Ti:W ratio drops by as much as 30% in films deposited at high (6kW) power levels compared to those at low powers (1–3kW), which were already a factor of two below the target composition. As mentioned above, we believe the Ti:W ratio in our zero bias films is nearly equal to that in the target.

A few runs were made at different power levels with zero bias to see if resistivity and Ti:W ratio were affected. No runs were made at high powers because experience has shown that there is a danger of target cracking. The table below indicates that there is an increase in the Ti:W ratio with a decrease in power from two to one kW.

Table I. Effect of Power on Composition and Resistivity

Run	Power, kW	Relative Ti:W ratio	Relative Resistivity
77-2	2.0	1.0	1.0
77-3	1.5	no sample	–
77-4	1.5	1.2	1.01
78-1	1.0	1.3	1.03
78-2	1.0	1.2	1.04

Care must be exercised in interpreting these, or any, results in which power levels are changed. At the very high power densities possible with dc magnetron sputtering, differential yields due to the mass effects discussed earlier tend to disappear. At high power levels the altered surface layer will tend to approach the bulk composition. If power is decreased, the initial sputtered material will be Ti – rich, until steady state conditions are achieved. Conversely, initial films made when power is changed from low to high will be relatively W – rich. When power is changed, a series of films should be made and properties of interest monitored until they are repeatable from run-to-run.

Rf Sputtered Films

In the case of rf sputtered films with rf substrate bias, the power is split between target and substrate holder. The rf forward power was held constant, so the power to the target decreased as the bias was increased. Thus, correlations of resistivity and concentration are made against substrate bias voltage, rather than bias power, as shown in **Figure 4**.

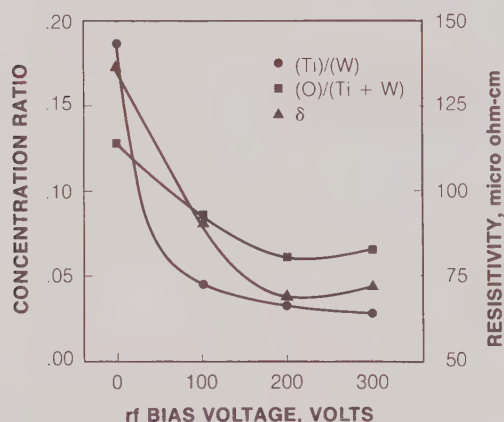


FIG. 4 Ti:W, oxygen: metal ratios, and resistivity vs rf substrate bias voltage for rf sputtered Ti:W films.

The Ti:W ratio for zero bias is higher than for the dc films. Hill also found higher ratios for rf sputtered films and attributed them to differences in power density. However, when we used the same target for rf and dc sputtering (see below), film compositions were the same.

The correlations of resistivity with bias voltage ($r = 0.90$), Ti:W ratio ($r = 0.97$), and O:M ($r = 0.99$) were all quite high. This indicates that both oxygen and titanium content were controlling resistivity, which is reasonable considering the high oxygen concentration for these films. The higher oxygen content, as compared to the dc sputtered films, is due to several factors. First, the

instantaneous deposition rate for the dc films was about four times the rf rate. Second, the base pressure of the 2400 system is higher than for the 4400. Finally, the pressure was not returned to high vacuum between etch and deposition.

As a test of differences in targets and vacuum systems the magnets were removed from the dc target and several films were made by rf sputtering without substrate rotation in the 4400 system. Even though the deposition rate was half that in the 2400 system (the uniformity shaper was not removed), the resistivity at zero bias was 100 micro-ohm cm, compared to 137 for the similar 2400 film, and 80–90 for the dc films sputtered at the same *average* rate. Both Ti:W and O:M ratios were comparable to the dc sputtered films. Thus, there may be an effect due to the process of rf sputtering, such as electron bombardment of the film, which results in higher resistivity compared to dc sputtering. For example, grain size or oxygen distribution could be affected.

Conclusions

It is possible to control, by means of rf substrate bias, the resistivity of both dc magnetron and rf sputtered Ti:W films so that it falls in the desired 60–90 micro-ohm-cm range.

The Ti:W ratio in the films decreases with increasing bias and is highly correlated with the film resistivity. Oxygen:metal ratio is also reduced by bias in films made in "dirty" vacuum environments and contributes to resistivity if it is above a value of about 0.05.

Auger analysis of Ti:W films appears to be affected by preferential sputtering of Ti during the profile. Relative concentrations between films should not be affected by preferential sputtering.

Target power may have an effect on film composition, but more work is required to confirm this.

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DEPOSITION OF ALUMINUM OXIDE BY RF DIODE SPUTTERING WITH RF SUBSTRATE BIAS

Ronald S. Nowicki and Donald G. Ward

This study describes a preliminary survey of the deposition parameters and physical properties of aluminum oxide thin films, RF diode sputtered in a Perkin-Elmer Model 2400-8L System. The areas of investigation include deposition power density vs. deposition rate, power density vs. deposition temperature, substrate bias vs. intrinsic film stress, step coverage, etch rate, pinhole density, refractive index and microhardness. It is shown that adequate step coverage and reduced film stress are found when substrate bias values near -25v are used. Adherent films up to 20 microns thick were prepared using the technique described herein.

Aluminum oxide thin films have been used as passivation layers on integrated circuit devices¹, due in part, to their alkali barrier² and radiation resistance properties³. They have also been used as abrasive-resistant layers on thin film thermal printheads⁴. Extensive studies have been reported by Kennedy⁵ on the properties of RF diode sputtered aluminum oxide. More recently, an investigation on the properties of aluminum oxide deposited by RF magnetron⁶ indicated that the films were non-optimal from the standpoint of step coverage and pinhole/defect density. Moreover, it appeared that RF substrate biased deposition was an essential parameter in the control of these film properties, as shown by Kennedy's study.

This study was undertaken in an attempt to show that this parameter could be used to advantage in the Perkin-Elmer system without modifications to the system. Additional data will concern substrate temperature effects, film etch rate, refractive index and microhardness.

All depositions were done in a Perkin-Elmer Model 2400-8L sputtering system equipped with load lock, turbomolecular pump and Welch Model 1397 roughing pump (**Figure 1**). The sputtering target was hot-pressed three nines purity aluminum oxide, 20cm in diameter

and ca. 6mm thick, solder-bonded to a water-cooled copper backing plate. The RF diode depositions were done with a target-to-substrate spacing of ca. 3.8cm at a typical base pressure of $<2 \times 10^{-6}$ Torr (2.7×10^{-4} Pa) using 10m Torr (1.33 Pa) argon (UHP) as sputtering gas. Power density values were calculated using RF power as distributed over the entire target area, which is somewhat inaccurate in a strict sense, but is viable for comparisons. Film thicknesses were determined with a Tencor profilometer after etching a step in the film in $\text{HF}:\text{H}_2\text{O}$ (1:5). Laser ellipsometry (Applied Materials) was used when appropriate and when measuring film refractive index. Deposition temperature was measured with a surface thermometer (PTC) placed directly upon the substrate holder (pallet). Film stress was calculated from the curvature of thin ($75\mu\text{M}$) glass beams, 6mm wide and 25mm long via the method of Kinosita⁷. Pinhole density was determined by an Atomel Pinhole Detector (Applied Materials) at ca. 50v bias on 76mm diameter (100) silicon wafer substrates.



FIG. 1 Perkin-Elmer Model 2400-8L Sputtering System.

Deposition Rate vs. Power Density

Figure 2 shows the variation in deposition rate vs. RF power density and RF substrate bias. It appears that a slight improvement in deposition rate exists for depositions done at -25v bias in comparison to "no bias" depositions; while a decrease in rate was obtained for films deposited in 1% oxygen-argon.

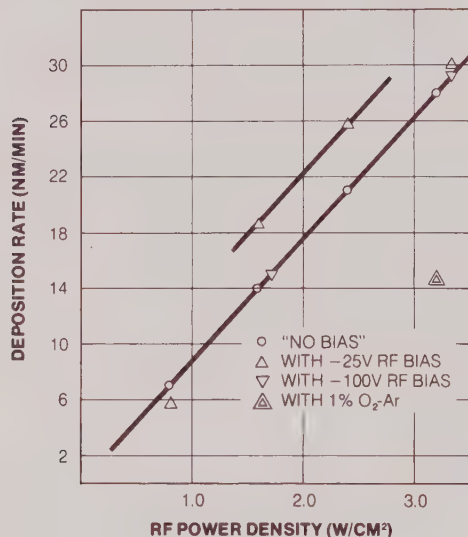


FIG. 2 Plot of deposition rate vs RF power density.

Deposition Temperature vs. Power Density

Deposition temperature, as measured by a surface thermometer, vs. power density was determined in the biased mode (-25v). **Figure 3** shows the resultant plot. From **Figure 3**, it is interesting to note that deposition temperatures exceeding 300°C are achieved at a power density of ca. $3.5\text{W}/\text{cm}^2$. It is likely that substrate table rotation may reduce these temperatures.

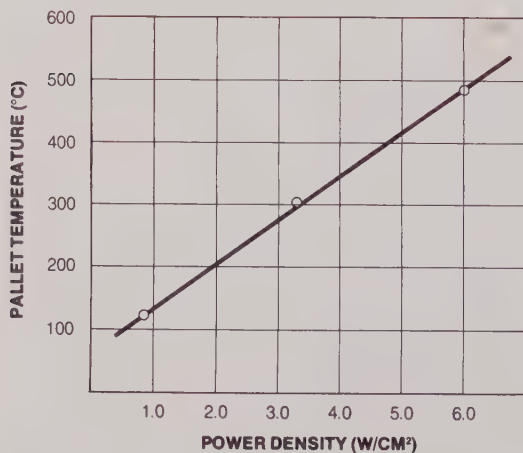


FIG. 3 Plot of deposition temperature vs RF power density.

Film Stress vs. Substrate Bias

Since one of the goals of this study was to deposit thick films ($>10\mu\text{M}$) of aluminum oxide with good adherence, it was apparent that film stress was a crucial parameter in need of investigation. In particular, the influence of substrate bias on this property was chosen due to the reported profound effect of this parameter on film stress.⁵ **Table I** shows the results of the present study, wherein intrinsic film stress of ca. one micron thick aluminum oxide films was studied as a function of RF substrate bias. From **Table I**, it is interesting to note that minimal values of film stress are found near the region between -25v and -50v bias. Moreover, from the higher value of stress observed under "no bias" conditions, it is apparent that the use of RF bias to reduce film stress in aluminum oxide films is a viable technique. The usefulness of this technique was further substantiated by the fact that $20\mu\text{M}$ thick films could be easily deposited onto ferrite substrates at $6\text{W}/\text{cm}^2$ and -25v bias without indication of film cracking. This thickness of film could not be deposited under "no bias" conditions, where there was evidence of stress-induced cracking at thicknesses $>10\mu\text{M}$.

Table I. Properties of RF Sputtered Aluminum Oxide Films^a

Sample Code	RF Bias (V)	Thickness (KÅ)	Stress ($\times 10^9 \text{ dyn/cm}^2$)	Pinhole Density (defects/cm ²)
1	"NO BIAS"	9	5.9	68
2	0	7.5	2.8	68
3	-25	13.5	3.4	64
4	-50	11.5	2.7	—
5	-75	12.5	4.3	10
6	-100	8.0	11.4	2
7 ^b	-25	4.6	5.9	—

^a All depositions were done at $1.7 \text{ W}/\text{cm}^2$ power density in 10 mTorr argon. Film stress was compressive in all samples.

^b Deposited in 1% oxygen:argon (10 mTorr).

Step Coverage

In earlier literature concerning sputtered oxide deposition^{8,9,10}, it was demonstrated that RF substrate biasing was essential for coverage over steep topography when complementary substrate heating was not employed. **Figure 4** shows SEM micrographs of aluminum oxide step coverage over a $4\mu\text{M}$ metal conductor line for depositions done with "no bias" and -25v bias. From **Figure 4**, it is apparent that microdefects exist in the aluminum oxide film deposited with "no bias", whereas excellent coverage with no observable defects exist in the -25v biased film. Confirmation of the degree of "edge protection" was obtained by immersion of the biased sample from **Figure 4** in the metal etchant. No metal attack was seen

after 5 hours under conditions which would etch the metal at ca. 1000 Å/min. Identical treatment of films deposited under "no bias" conditions resulted in metal attack after only a few minutes, similar to that reported by Logan, et al.⁸

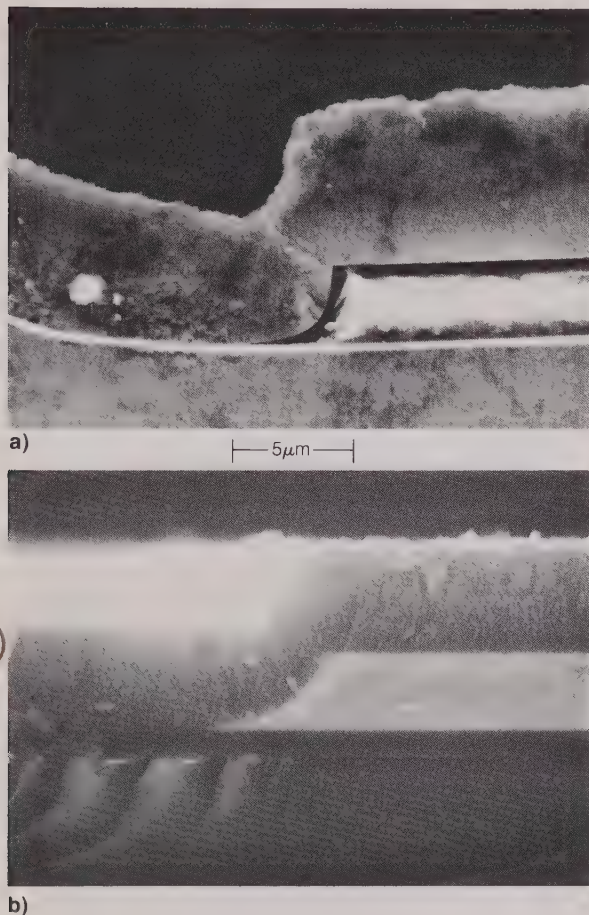


FIG. 4 SEM micrographs showing
a) step coverage of aluminum oxide
RF sputtered with "no bias" (floating)
and b) RF sputtered with -25v bias.

Etch Rate

The etch rate for an aluminum oxide film (0.5μm thick) deposited at -25v bias was found to be ca. 170 Å/min. in 1:5 HF at room temperature.

Pinhole Density

Table I shows the values for pinhole density found in sputtered aluminum oxide films deposited at 1.7 W/cm² at 0, -25, -75 and -100v substrate bias. From **Table I**, it is obvious that pinhole-type microdefects are minimized by the use of RF bias, as shown earlier by Logan, et al.⁸

Refractive Index

The refractive index of aluminum oxide deposited at -25v bias and 1.7W/cm² was found to be 1.63.

Microhardness

The microhardness of a 7μm thick aluminum oxide film deposited at -25v bias and 1.7W/cm² was comparable to bulk sapphire (Vickers Method).

Summary

From the above data, it is apparent that RF substrate bias is a key parameter in the sputter deposition of optimal aluminum oxide films in the Perkin-Elmer 2400 system. This data, and that reported in the literature, indicates that this parameter is probably crucial to the deposition of optimal oxide films in general.

This data, however, also indicates that some compromises may have to be made between low pinhole density and intrinsic film stress, i.e. the substrate bias values necessary for low pinhole density appear to yield high intrinsic film stress. Thus, the choice of actual deposition parameters rests with the process engineer, and will be determined to some extent by other post-deposition processing which may affect these film properties.

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COMPARISON OF THE PROPERTIES OF MOLYBDENUM SILICIDE FILMS DEPOSITED BY DC MAGNETRON AND RF DIODE CO-DEPOSITION*

Ronald S. Nowicki and John F. Moulder

This is a preliminary study in which the physical and electrical properties of DC magnetron and co-deposited RF diode molybdenum silicide films of varying stoichiometry are compared. It is shown that the DC magnetron films tend to be non-optimal in comparison to the RF diode co-deposited films of the same stoichiometry. Extensive degradation of the DC magnetron films was frequently observed during heat treatment at 1000°C in nitrogen or argon ambient. The RF diode films, however, appear to withstand heat treatment without signs of degradation. There appear to be significant differences in film stress changes during heat treatment. The DC magnetron films exhibit a severe change in stress level resulting in a highly tensile state. This causes film cracking and loss of adhesion, whereas the RF diode co-deposited film stress changes to minimal values during heat treatment. Additional data on crystal morphology, resistivity change during heat treatment and general film properties are also discussed.

Refractory metal silicides have been proposed as alternatives to polycrystalline silicon (polysilicon) for gate electrode or interconnection metallizations in field effect transistor devices of VLSI dimensions.¹⁻⁴ This trend has evolved as a consequence of the prohibitive values of resistance encountered in conventional polysilicon gate technology as device geometries are reduced.

One significant problem with these newer materials appears to be the relatively high levels of contaminants (e.g. oxides, carbon and alkalis) presently

found in composite, hot-pressed sputtering sources (targets). These contaminants not only can alter device characteristics irreversibly, but may also result in the loss of film integrity during subsequent high-temperature (1000°C) device processing steps.

The high levels of intrinsic film stress often found in refractory silicide thin films is another potential problem. Additionally, many commercial sputter deposition systems do not provide a means of controlling this film stress through controlled DC or RF substrate bias.^{5, 6} Films deposited with high levels of intrinsic stress can also fail in subsequent high temperature processing, where thermal expansion coefficient mismatch between film and substrate is exaggerated.

This preliminary study describes a co-deposition technique in which RF sputtering is done from separate high purity targets of the refractory metal and silicon, with and without substrate bias. Additionally, it compares the physical and electrical properties of molybdenum silicide films, prepared by this technique, with films deposited by the DC magnetron technique.

DC Magnetron Deposition of Molybdenum Silicide

All DC magnetron depositions were done in a Perkin-Elmer Model 4400 cryopumped sputtering system equipped with a hot-pressed source (target) of molybdenum disilicide of 99.9 purity (Metron). The target was solder-bonded to a standard water-cooled copper backing plate and magnet assembly. Depositions were done at ca. 7W/cm² (averaged over entire target area of ca. 300cm²) and 5m Torr (0.67 Pa) of argon pressure at system base pressure of ca. 5 x 10⁻⁷ Torr (7 x 10⁻⁵ Pa) and 10 rpm substrate table rotation. Deposition rates were typically ca. 35nm/min. Films of ca. 250nm nominal thickness, determined via profilometry of an etched step (HNO₃ : HF-200 : 1), were deposited onto silicon wafers previously coated with ca. 100nm of thermal silicon oxide, 100nm of RF sputtered silicon nitride, and ca. 500nm of LPCVD-deposited (640°C) polycrystalline silicon. Additional depositions, with and without RF substrate bias, were done onto 5 x 25mm, 63μm thick sapphire beams for evaluation of film stress and film integrity during subsequent heat treatment.

Deposition of Molybdenum Silicide Via the RF Diode Co-deposition Technique

These depositions were done in the same sputter system described above from separate targets of

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99.99 purity molybdenum and silicon using the RF power-splitting feature of the system at 10m Torr (1.33 Pa) argon pressure. For deposition of the silicon-rich ($\text{MoSi}_{2.8}$) films, typical target voltages and wattages were: Mo – 850V, 300W; Si – 2400V, 1500W. Substrate pallet rotation was 10 rpm in all cases. Under these conditions, ca. 0.1nm of molybdenum and ca. 0.2nm of silicon were deposited per one pallet revolution. The resultant deposition rate was ca. 2.7nm/min. Deposition temperature was found to be ca. 100°C under these conditions (PTC Model 575 CM surface thermometer).

To study the influence of RF substrate bias on the film properties, additional depositions were done with varying degrees of bias. The effects of this parameter are discussed later in the text.

Additional RF diode depositions were done from a composite target of 99.9 purity at 10m Torr argon pressure and 5W/cm² power density. The resultant deposition rate was ca. 4.7nm/min.

Experimental Techniques

Conventional four point probe measurements were used for resistivity determinations.

All heat treatments were carried out with a Lindberg "table top" (Model SB 54542) furnace and quartz diffusion tube using high-purity sources of nitrogen or argon at ca. 10 l/min. flow.

CV plotting was done with an MDC controller/plotter and Signatone probe with hot stage.

Auger and SIMS analyses were done with a Perkin-Elmer Model 590 Scanning Auger Microprobe.

The elemental sensitivity values reported by Davis, *et al.*,⁷ were used to quantify the Auger electron spectra.

Helium ion backscatter analysis was done with the Cal Tech 3 MeV Van de Graaff accelerator using 4He^+ ions in the technique reported by Chu, *et al.*⁸

Scanning electron microscopy (SEM) was done with a Hitachi S-450-1 system.

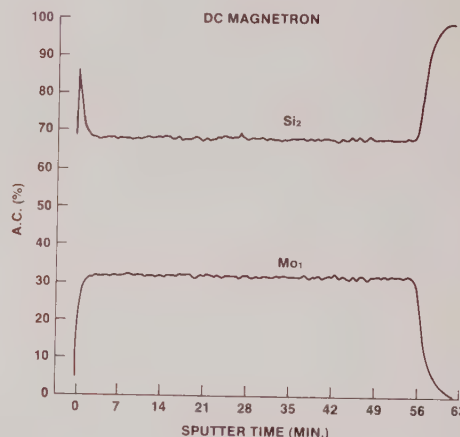
Determination of film stress was done on thin sapphire beams using the method reported⁹ earlier.

X-ray diffractometry was done with a GE XRD diffractometer using $\text{CuK}\alpha$ radiation at 35KV.

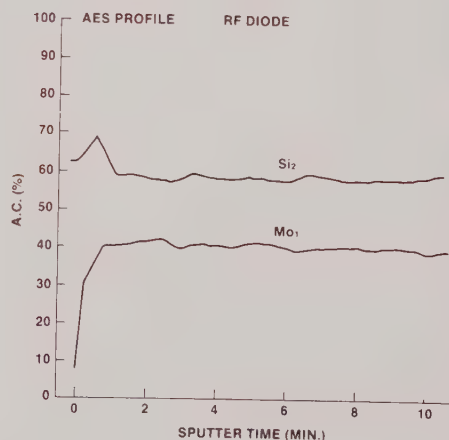
Determination of Molybdenum-Silicon Stoichiometry

Molybdenum/silicon ratios for both DC magnetron and co-deposited RF diode films were initially determined in films deposited directly on silicon wafers. This was essential for the co-deposited films, where no prior correlations existed between deposition parameters and stoichiometry. It was hoped that the DC magnetron and RF diode films deposited from a single composite target of $\text{Mo}_{33}\text{Si}_{67}$ would serve as "standards" for the stoichiometric determinations. However, it can be seen (**Figure 1**) that good stoichiometric correlation between the two deposition methods was not obtained, as shown by the Auger

depth profile plots of the resultant films. It is apparent that the molybdenum/silicon atomic ratio appears to be ca. 32:68 for the DC magnetron films, whereas the ratio appears to be ca. 39:61 for the RF diode films.



(a)



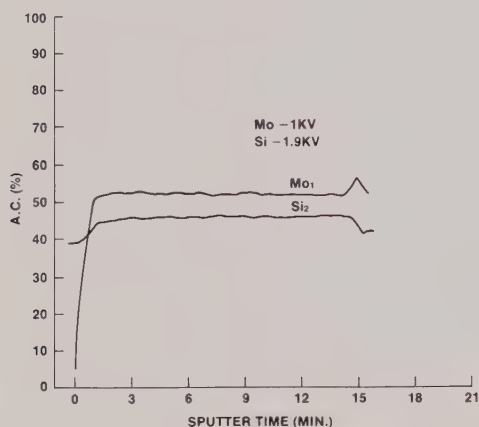
(b)

FIG. 1 Auger depth profile plots of (a) DC magnetron and (b) RF diode films sputtered from single composite targets of composition $\text{Mo}_{33}\text{Si}_{67}$.

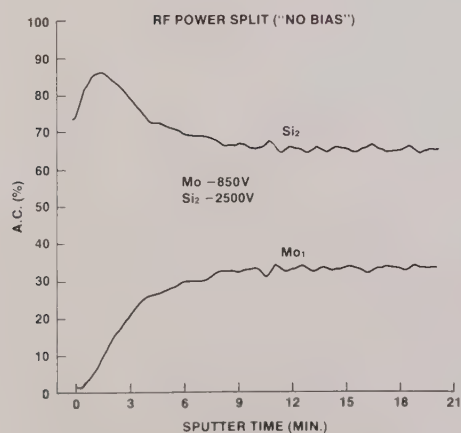
In an attempt to resolve the question of film stoichiometry and to obtain a "standard" film, a sample of an RF diode co-deposited film having an apparent Mo/Si ratio of 32:68 by Auger analysis was analyzed via helium ion backscattering spectrometry (HIBS). The resultant Mo/Si ratio was found to be 26:74. Since the HIBS analyses are assumed to have an accuracy of approximately $\pm 5\%$, it is apparent that the Auger results are providing ratios that are Mo rich. It is possible that either differential sputtering effects or matrix effects on the shape of the Auger lines

contributed to this error.¹⁰ If the error is assumed to be constant (which may not be the case) a correction factor can be obtained by comparing the Auger and HIBS data. In this case the HIBS Mo/Si ratio was .35; the Auger Mo/Si ratio was .47. Therefore, a correction factor of .74 should be used to correct the Auger data.

Figure 2 presents the Auger depth profile plots which depict the stoichiometry of two RF diode films, co-deposited with differing target voltages on the molybdenum and silicon. Application of the above correction factor to these plots results in stoichiometric ratios of (a) $\text{Mo}_{46}\text{Si}_{54}$ and (b) $\text{Mo}_{26}\text{Si}_{74}$. For simplification, these films will be designated (a) MoSi and (b) $\text{MoSi}_{2.8}$.



(a)



(b)

FIG. 2 Auger depth profile plots of RF diode co-deposited molybdenum silicide films sputtered at different target voltages.

Comparison of Morphology and Integrity of As-deposited and Heat-Treated DC Magnetron and RF Diode Films

The as-deposited films from all three types of de-

positions were metallic in appearance and exhibited no visible crystallinity or surface features at magnification up to 30KX (SEM) on silicon oxide or nitride-coated silicon and sapphire. On polysilicon, all the as-deposited films tended to replicate the crystal morphology of the polysilicon. This observation is evident in **Figure 3a**, which shows the morphology of undoped polysilicon before (insert) and after deposition of the DC magnetron molybdenum silicide without substrate bias. When this structure was subjected to 1000°C heat treatment for 30 minutes in nitrogen or argon, severe cracking was observed in many instances, as shown in **Figure 3b**. Additionally, white fumes, presumably molybdenum oxide, evolved from the film during heat treatment.



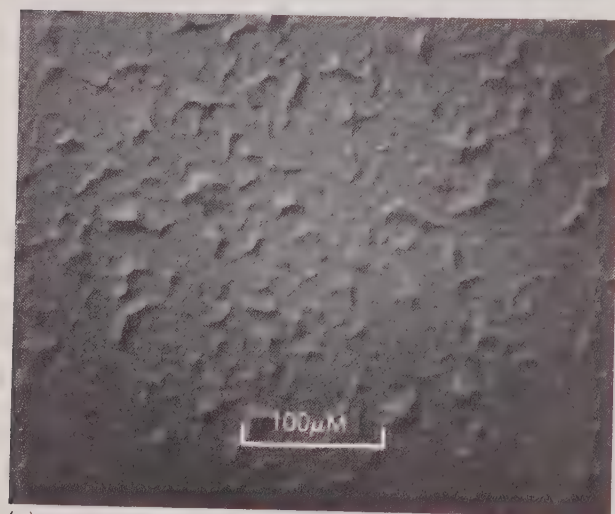
(a)



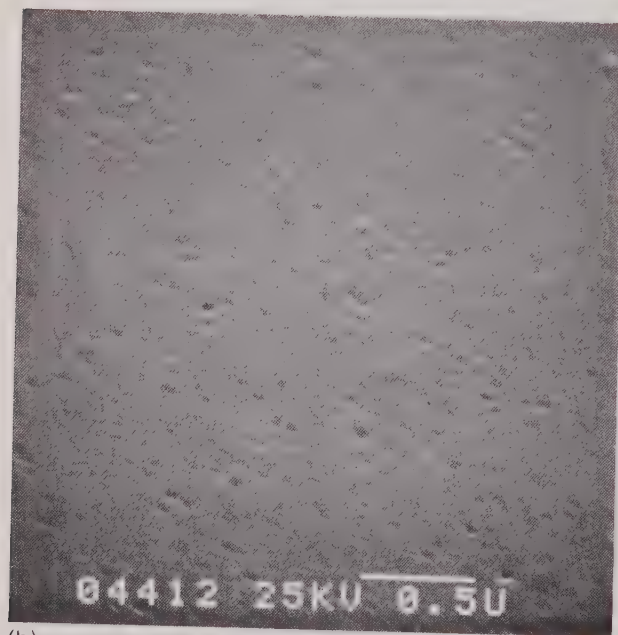
(b)

FIG. 3 SEM micrographs of DC magnetron sputtered molybdenum silicide films on polysilicon, (a) as-deposited and (b) heat treated in nitrogen at 1000°C for 30 minutes. Insert (a) shows the uncoated polysilicon surface.

The severity of this degradation precludes further processing. From **Figure 3**, it appears that these cracks are associated with a grain boundary, or film stress phenomenon. The film stress-induced mode of degradation is supported by the observation that the films tended to peel away from the substrate with concavity **Figure 4a**, indicative of tensile stress in the film. (See Film Stress section for further comment.) This degradation is more severe in films deposited under high values of substrate bias (-120V).



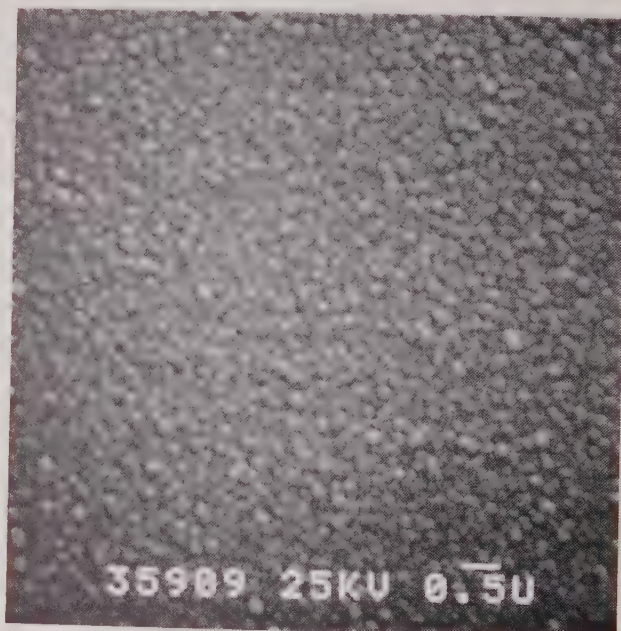
(a)



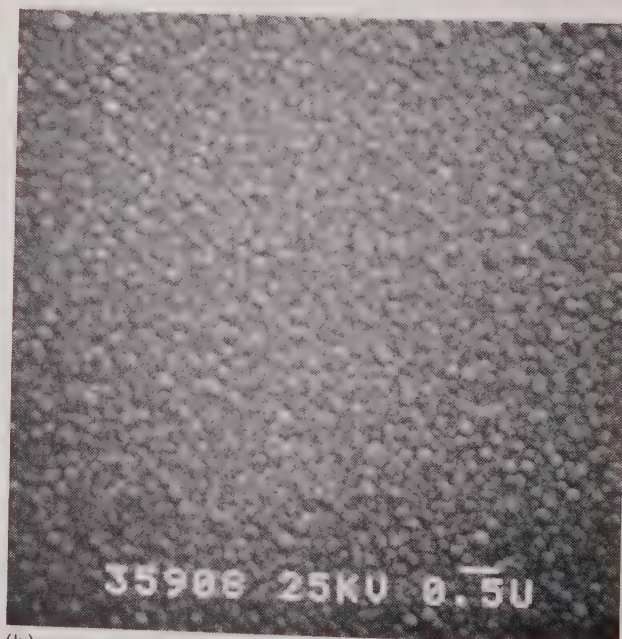
(b)

FIG. 4 Micrographs of (a) heat treated DC magnetron molybdenum silicide on polysilicon showing peeling morphology, and (b) heat treated $\text{MoSi}_{2.8}$ on oxide.

For RF diode co-deposited films having Mo/Si ratios <0.5 on polysilicon, silicon oxide or nitride, no observable film degradation was observed during and after heat treatment, as shown by **Figure 4b** and **Figure 5**. It should be noted that the largest visible crystallites (**Figure 4b**) were $<100\text{ nm}$ in width.



(a)



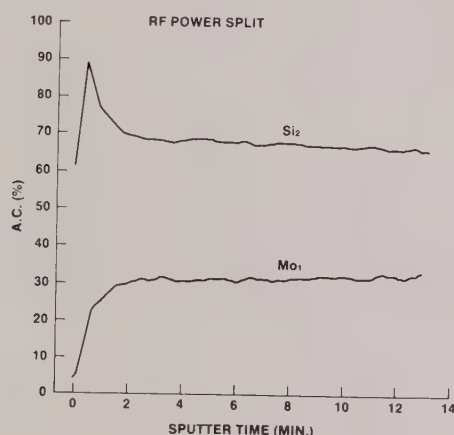
(b)

FIG. 5 SEM micrographs showing (a) as-deposited and (b) heat-treated $\text{MoSi}_{2.8}$ on polysilicon.

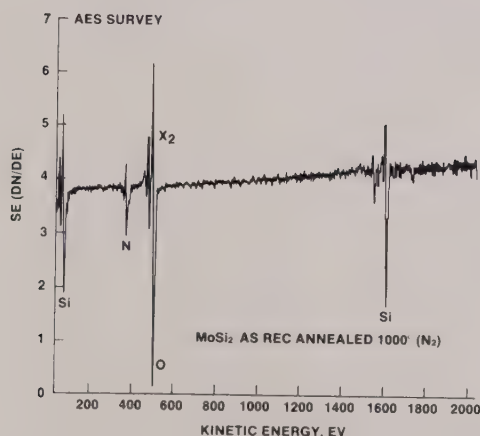
Auger depth profile analysis of the films deposited under RF bias indicated that Mo/Si stoichiometry remained unchanged as a result of the heat treatment

(Figure 6a) when the Mo/Si ratio was <0.5 . However, one change which became apparent during heat treatment was the appearance of a thin (ca. 5nm) layer of silicon nitride on the surface of the silicide film.

Figure 6b shows the Auger spectrum of the heat-treated film. No molybdenum was detected on the surface. The nitrogen peak, however, is readily apparent in the spectrum. For co-deposited films of molybdenum-rich stoichiometry ($\text{Mo/Si} > 0.5$), extensive surface degradation was observed during heat treatment. It should be noted that no detectable changes in thickness were observed for MoSi or $\text{MoSi}_{2.8}$ films on silicon nitride or oxide as a result of heat treatment.



(a)



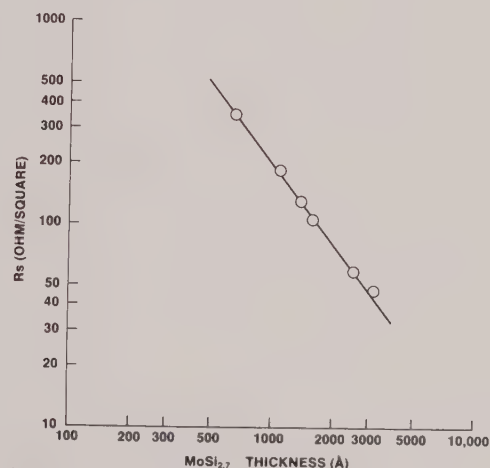
(b)

FIG. 6 Auger analyses showing (a) depth profile of heat-treated RF diode co-deposited molybdenum silicide having as-deposited composition of $\text{Mo}_{32}\text{Si}_{68}$ (Auger), and (b) AES survey of film surface.

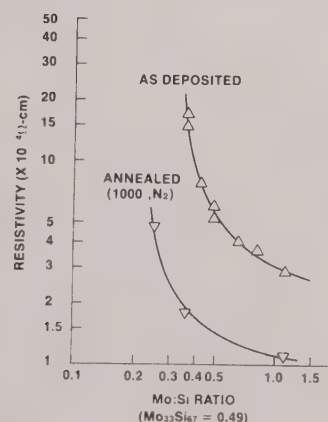
Comparison of the Electrical Properties of the DC Magnetron and Co-Deposited RF Diode Films

The as-deposited DC magnetron films had sheet resistance of ca. $20\Omega/\text{sq.}$ on silicon oxide or nitride. After heat treatment at 1000°C in nitrogen or argon, the sheet resistance lowered to $4\text{--}5\Omega/\text{sq.}$ in cases when the film integrity was retained.

For the RF diode co-deposited films, the as-deposited sheet resistance values were dependent upon molybdenum-silicon stoichiometry, as expected. Figure 7a shows the sheet resistance values plotted as a function of thickness for the composition $\text{MoSi}_{2.7}$. Figure 7b shows the resistivity plots as a function of Mo:Si ratio for as-deposited and heat-treated molybdenum silicide films of varying composition deposited under "no bias" (floating) conditions. With biased substrate depositions, -25 to 50V , the heat-treated film resistivity appears to lower ca. 50% from the values shown. Thus, resistivity values of ca. $8 \times 10^{-5}\Omega\text{cm}$ can be obtained.



(a)



(b)

FIG. 7 Plots showing (a) sheet resistance vs. thickness for $\text{MoSi}_{2.7}$ and (b) as-deposited and heat-treated film resistivities for molybdenum silicide films of various stoichiometry.

Capacitance-voltage plots of the DC magnetron and RF diode co-deposited films were done before and after heat treatment after using a metal mask to define 750 μ m diameter electrodes of the silicide on ca. 100nm of thermal oxide on *n*-type silicon wafers. **Figure 8** shows the resultant plots for the as-deposited DC magnetron film and the RF diode film after heat treatment. The plot for the as deposited RF diode film is not shown due to its severe distortion, presumably due to oxide "damage" during deposition. From **Figure 8**, it is apparent that alkali and hydrogen-induced flatband shifts (Q_m)¹¹ are excessively high (ca. 3×10^{12} charges/cm²) for the DC magnetron films, whereas the heat treated RF diode films have Q_m values of ca. 8×10^{10} /cm². The high Q_m values of the DC magnetron films were considerably reduced to levels comparable to the RF diode films after heat treatment at 1000°C in cases where film degradation did not occur. This reduction in Q_m with heat treatment was reported by Learn.¹²

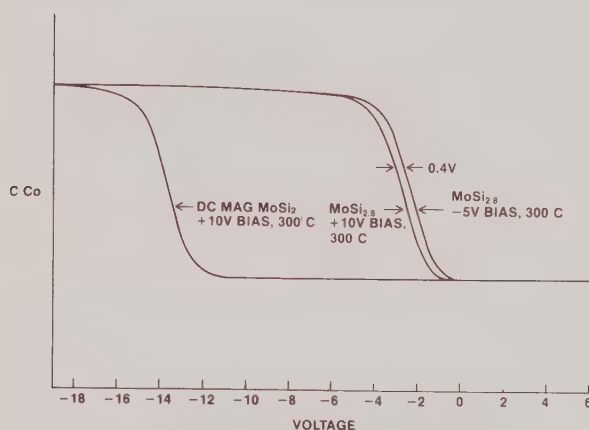


FIG. 8 Capacitance-voltage plots of as-deposited DC magnetron film and heat-treated RF diode co-deposited MoSi_{2.8} film.

X-ray Diffractometry

X-ray diffractometry was done on the as-deposited and heat-treated DC magnetron and RF diode co-deposited films on silicon nitride coated wafers. The resultant spectra are shown in **Figure 9**. Examination of these spectra show that both the as-deposited DC magnetron and RF diode films (**Figure 9a**—their spectra were superimposable) exhibited minimal crystallinity. The silicon (211) cubic reflection in these spectra may be attributable to unreacted silicon in the as-deposited films. The intensity of this reflection is considerably diminished, or absent, after heat treatment. Additionally, the heat treated DC magnetron film (b) shows strong tetragonal MoSi₂ reflections only. The RF diode co-deposited film designated MoSi (c) shows tetragonal and hexagonal MoSi₂ and cubic Mo₃Si reflections, whereas the film designated

MoSi_{2.8} (d) shows only weak tetragonal MoSi₂ reflections consistent with the SEM micrograph shown earlier (**Figure 4b**), indicative of very small crystallite size.

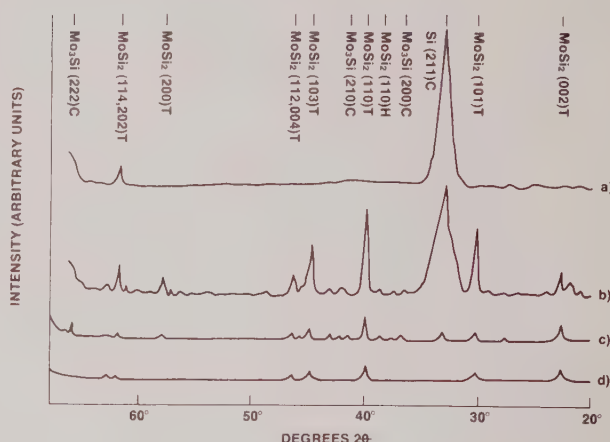


FIG. 9 X-ray spectra showing (a) as-deposited DC magnetron and RF diode co-deposited MoSi_{2.8} films, (b) DC magnetron film after heat treatment, (c) MoSi and (d) MoSi_{2.8} films after heat treatment.

Film Stress

In the as-deposited DC magnetron films on sapphire, film stress was compressive and was calculated to be ca. 1×10^{10} dyn/cm². During 1000°C heat treatment, however, the intrinsic film stress changed to high tensile stress values. This change could actually be observed during heat-up of the film—the substrate could be seen to curl rapidly from a convex to a concave condition, after which the film would tear away from the substrate producing fine particulates. In extreme cases, silicon wafers were seen to fracture during heat treatment¹³, especially when the deposition was done under high (–120V) substrate bias.

No such degradative changes in film stress were observed with the RF diode co-deposited films having Mo/Si ratios between 0.33 and 0.5. As-deposited, the film stress was minimally unmeasurable for films sputtered under "no bias" conditions or at –75V bias. Between –25 and –50V bias, film stress was ca. 5×10^{10} dyn/cm² (compressive). However, 1000°C heat treatment of these films yielded a reduction of this stress to unmeasurable values. For films having Mo/Si ratios between 1.0 and 0.5, the film stress appeared to be in varying degrees of tension. Heat treatment also appeared to reduce this stress to unmeasurable values. This stress behavior during heat treatment differs from that reported¹⁴ for co-sputtered titanium silicide.

Analysis of Trace Elements

Analysis for trace elements and hydrogen was

done on the as-deposited DC magnetron and RF diode co-deposited films using the SIMS capability of the Perkin-Elmer Model 590 system. Additionally, film samples were also electron beam heated *in situ* and the resultant evolved gases were measured by mass spectrometry. The resultant spectra showed hydrogen and fluorine to be present in all the films.

Step Coverage

A 250nm thick co-deposited film of composition $\text{MoSi}_{2.8}$ was sputtered onto an oxide-stepped silicon wafer at -50V substrate bias. The film was heat treated at 1000°C , then photolithographically masked and etched in a parallel plate prototype reactor using Freon-14 as the etch gas. **Figure 10** shows the SEM micrograph (in cross section) of the etched film over a one micron oxide step which is slightly "undercut". From **Figure 10**, it is apparent that acceptable step coverage was obtained in the as-deposited film.

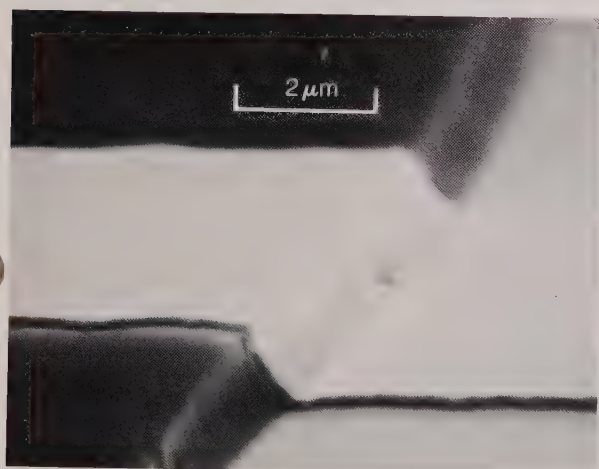


FIG. 10 SEM micrograph showing coverage of RF diode co-deposited film over oxide step.

Oxidation Rate

RF diode co-deposited films of composition $\text{MoSi}_{2.8}$ and MoSi_2 were oxidized in dry oxygen at ca. 6 l/min. flow at 1000°C . The resultant oxidation rate for the $\text{MoSi}_{2.8}$ was only ca. $3\text{\AA}/\text{min}$, whereas the rate for the MoSi_2 was ca. $400\text{\AA}/\text{min}$. Additional studies are underway in an attempt to gain more information on the oxidation of these films.¹⁵

Conclusions

This study has shown that molybdenum silicide films deposited by DC magnetron sputtering tend to be non-optimal during subsequent heat treatment, i.e. film degradation is often encountered for no easily apparent reason. The problem is more acute for films deposited under high values (-120V) of RF substrate bias.

RF diode films co-deposited from separate sources of molybdenum and silicon, however, do not exhibit this degradation when the Mo/Si ratio is ≤ 0.5 . The reason for the difference in behavior between the DC magnetron and RF diode co-deposited films is unclear at the present time. A possible model for the degradation is that trace impurities, e.g. hydrogen, in the DC magnetron films may result in severe changes in film stress during subsequent heat treatment. This severe change in film stress level is indeed observed during heat treatment of the DC magnetron films and is not observed with the RF diode co-deposited films. However, film analysis by Auger and SIMS shows little differences, if any, in trace element content between the two types of films. Thus, it may be possible that the instrumental sensitivity to trace elements is insufficient to allow for correlations with film properties. However, the Auger analyses done on the RF diode co-deposited films were shown to be essential for the establishment and monitoring of molybdenum-silicon stoichiometry in such a study.

In summary, it appears that the RF diode co-deposition technique is viable for the production of good quality molybdenum silicide films of low resistivity. Fully-operational gate arrays have been fabricated from these films, thus supporting the feasibility of the technique. Additionally, this technique has been extended to other refractory metal silicides with similar results.¹⁶

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COPPER DISTRIBUTION IN SPUTTERED AL/CU FILMS

D.R. Denison and L.D. Hartsough

The copper distribution in sputtered aluminum-copper films depends on copper concentration and deposition temperature. At high deposition rates, the film temperature is high enough for diffusion to occur without external substrate heating. Targets containing 0.5, 2 and 4 percent copper were used to deposit films by DC magnetron sputtering. No segregation was found in the 0.5 percent Cu films at film deposition temperatures as high as 460°C. The 2 and 4 percent Cu films showed segregation, with the peak in the copper content located nearer the film-substrate interface.

Copper is added to aluminum for use as a conductor layer in semiconductor integrated circuit fabrication to provide electromigration resistance¹ and inhibit hillock growth.^{2,3} In the past, this alloy has been deposited from single or dual evaporation sources. More recently, high rate planar magnetron sputtering has shown the capability of producing films with good step coverage, low resistivity, high specularity,⁴ low hillock density,⁵ and repeatable alloy content.^{5,6}

During sputter deposition, the film temperature is determined by the condensation rate, the kinetic energy of arriving atoms (both target and reflected argon), the flux of electrons, and uv radiation from the glow discharge.⁷ Although the cathode magnetic field and the anode minimize substrate bombardment by electrons, the other sources of energy provide a substantial heat input to the film of approximately 300 Kcal/mole of deposited aluminum.⁷ Thus, a simple calculation shows that equilibrium film temperatures above 500°C can be achieved with deposition rates in excess of 10 kÅ/min.

This study was initiated to determine the dependence of copper distribution within films on target composition and deposition rate (and thus, temperature) and to follow changes in copper distribution after annealing. These data are compared with some results for evaporated films.

Experimental Procedure

The films studied were produced in a

Perkin-Elmer Model 4410 sputtering system. This system was chosen because of the wide range of deposition conditions possible. The Delta™ DC planar magnetron sputtering cathode permits deposition rates as high as 12 kÅ/min and the rotary table permits investigation of single and multipass deposition. In the multipass mode, the substrates pass under the cathode and then have a period of time to cool before another pass under the cathode. No reactive gas was present with a partial pressure higher than 5×10^{-7} Torr, so contamination of the aluminum during the non-deposit portion of the table rotation was minimal. This was substantiated by the fact that films of pure aluminum were obtained with resistivity equal to that of bulk aluminum, 2.7 micro-ohm-cm. The deposition rate on the substrate as it passes beneath the cathode will be referred to as "instantaneous" rate. For reasons to be discussed, the table rotation was 2 rpm for all depositions. Net rates are about one sixth of the instantaneous rates for multipass deposition. For comparability, all films analyzed were approximately 10 kÅ thick. Thus, deposition time was increased as rate was decreased. Auger depth profiles of the film composition were obtained on either a Perkin-Elmer Model 545 or Model 590 Scanning Auger Microprobe. After deposition, the substrate was divided into two pieces. One piece was profiled as deposited and the second was profiled after an anneal of 500°C. Except where noted, the anneal was for one half hour.

Aluminum with 0.5, 2 and 4 percent copper were selected for study. The 0.5 percent copper alloy also contained 1 percent silicon, because this low copper content is primarily used for hillock suppression and the specularity was to be compared with that of aluminum -1 percent silicon films. The higher percentage copper films are of interest in providing electromigration resistance.

Film temperature was measured during the deposition cycle with a Vanzetti⁸ fiber optic infrared radiometer with a measurement range of 125–500°C. The fiber optic probe penetrated the vacuum chamber wall so that the substrate passed directly in front of it about 2 seconds after passing in front of the cathode. The probe is constructed so that the argon is inlet to the system through the fiber optic housing such that the face of the optic is in a viscous flow region, which helped to keep it from becoming coated by scattered aluminum atoms.

Results

Deposition of 4 percent copper films in the single pass mode at high rate (12 kÅ/min) resulted in film disruption on the trailing edge of a three-inch-diameter wafer. As seen in **Figure 1**, the film appeared to have melted and become agglomerated. It is felt that, because of segregation of the copper and high film temperature achieved, the 548°C eutectic in the Al/Cu system⁹ was reached. Even when the instantaneous rate was reduced to 10 kÅ/min, a single pass deposition raised the temperature high enough that whiskers grew from the film surface, as shown in **Figure 2**. These whiskers are up to several microns long and about 1 kÅ in diameter. The SEM used to take **Figure 2** was equipped with an energy dispersive X-ray attachment and analysis at high magnification showed the whiskers to be rich in copper. Quantitative analysis proved to be impossible because of the whiskers' small size. These film problems were eliminated by rotating the table at 2 rpm, so that a multipass deposition was obtained.

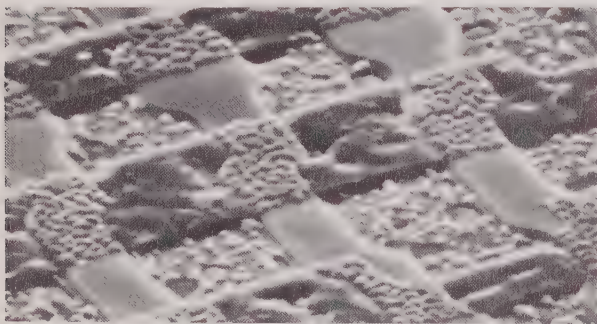


FIG. 1 Disrupted Al/4% Cu film deposited at 12 kÅ/min. in a single pass.

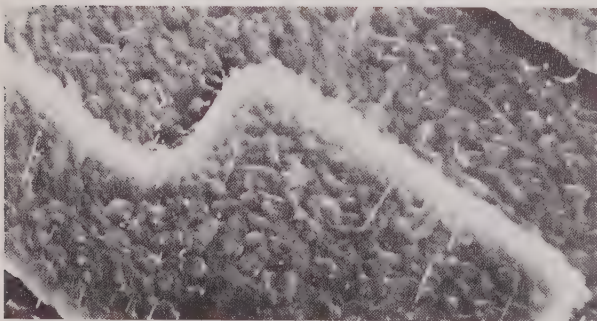


FIG. 2 Al/4% Cu film showing whisker growth.

Figure 3 shows the film temperature attained at the end of 2 rpm deposition of 10 kÅ thick films vs the instantaneous deposition rate. It is important to note that high enough temperatures can be achieved to permit diffusion of copper in the film and to substantially change the solubility of copper in the aluminum. **Figure 4** shows the solubility of copper in aluminum along with the film temperatures for the

samples. As shown, all of the 0.5 percent copper films were deposited in the single phase region, the 2 percent films were near the solubility limit, and the 4 percent films were all in the two phase region.

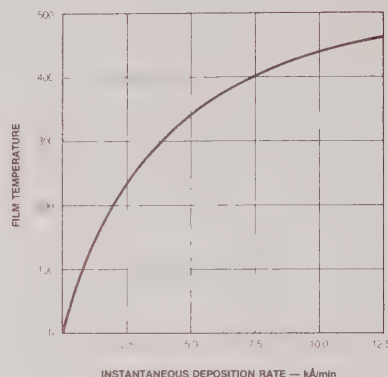


FIG. 3 Film temperature vs instantaneous deposition rate at 2 rpm table rotation speed.

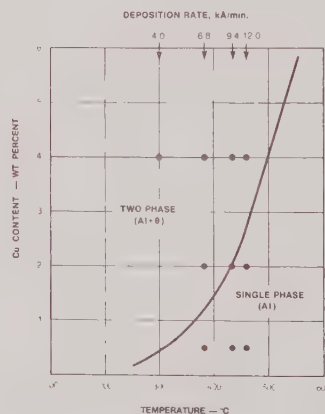


FIG. 4 Solubility of Cu in Al vs temperature. Data points show temperatures reached during deposition of the samples.

Figure 5 shows the copper distribution in the 0.5 percent alloy films. Even though this copper content represents excess copper at room temperature, the copper remained uniformly dispersed (within the 10-20 percent scatter of the data) at all deposition rates and film temperatures before and after anneal.

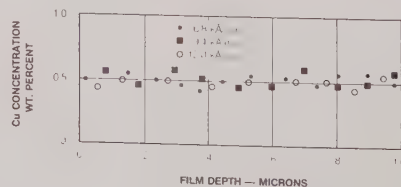


FIG. 5 Copper profile for as-deposited films containing 0.5% Cu. There was no change upon annealing.

The silicon also remained uniformly dispersed even though the silicon in an alloy without copper showed a strong tendency to segregate to the film interface with the substrate.³ The presence of 0.5 percent copper in aluminum very effectively suppresses hillock growth.¹⁰

Figures 6 and 7 show the distribution of copper in the 2 percent alloy films before and after anneal respectively. As deposited, the segregation was greater for the lower rate films which grew on the two phase side of the solubility curve. The maximum temperature achieved at 12 kÅ/min would be sufficient for uniform distribution of the copper if held long enough. The trend shown in **Figure 6** indicates that some redistribution occurred at the higher film temperatures, even though they were reached for a relatively short time. After anneal for ½ hour at 400°C, substantial redistribution of the copper occurred, with a thin copper-rich layer appearing at the free surface of the films, as shown in **Figure 7**.

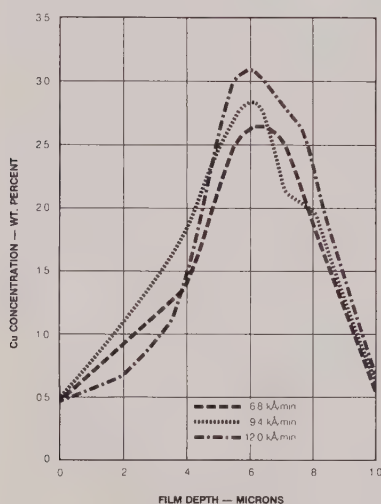


FIG. 6 Copper profile as-deposited for 2% Cu films deposited at 6.8, 9.4, and 12 kÅ/min., instantaneous rate.

Note that the apparent copper composition of the film is less than the 2 percent nominal target content. This is probably real, because the copper contents calculated from the integrated profiles of the 0.5 and 4 percent films are close to target compositions. In addition, the integrated copper content from **Figure 6** is also less than 2 percent. We do not know the source of this discrepancy.

Figures 8 and 9 show the as-deposited and as-annealed distributions of copper in the 4 percent alloy films. All films showed substantial segregation, even at relatively low deposition temperature, with segregation increasing with deposition temperature.

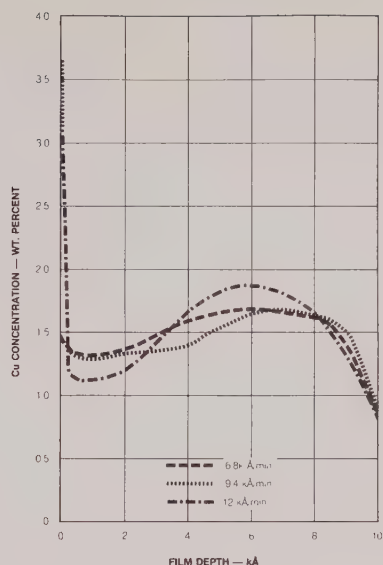


FIG. 7 Copper profile of Figure 6 films after anneal at 500°C for ½ hour.

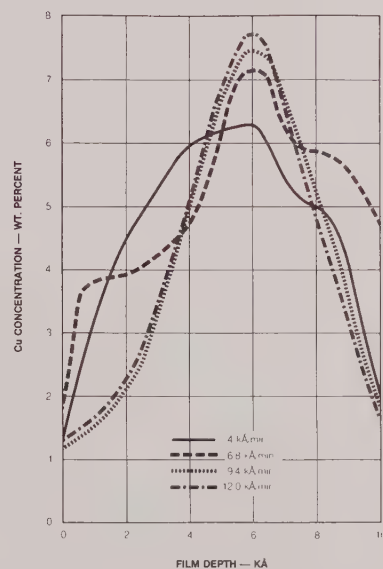


FIG. 8 Copper profile as-deposited for 4% Cu films deposited at 4.0, 6.8, 9.4, and 12 kÅ/min., instantaneous rate.

After anneal, however, these films showed quite different copper distribution characteristics depending on deposition temperature. For films made at low temperature, the copper segregated toward both film boundaries, with the higher concentration at the free surface. This agrees with the observations of Learn,¹¹ who studied films deposited by flash evaporation onto substrates at 350°C, and Mader and Herd,¹² who studied single crystal films deposited at

films could result from their lower copper concentration at the free surface, as compared to evaporated ones.

It is apparent that the kinetics of the sputter deposition process allow great variation in copper distribution by appropriate selection of the process parameters. Further work is necessary to determine how electromigration resistance is affected by use of deposition rate/table rpm to control film growth temperature. Evidence certainly exists¹⁶⁻¹⁸ that electromigration is affected by distribution and size of Θ -phase precipitates.

Acknowledgement

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REACTIVE ION ETCHING OF SiO_2 IN A LOAD LOCKED REACTOR

John R. Hollahan and Stefano Mangano

Reactive ion etching (RIE) has been extensively evaluated as an etching technique for semiconductor device development and manufacture. Although still abstruse in microscopic detail, the dominant kinetics attending etching processes are known well enough to permit their application to the etching of materials commonly used in device fabrication. The work described in this report was initiated to investigate the interrelationships between the design of the etching reactor and the etching process. The effects of gas flow and flow ratio control, system and substrate cooling and control, vacuum pumping configuration, and electrode and gas flow inlet configuration on the etching of SiO_2 over polysilicon are presented using a CF_4/H_2 gas mixture.

As semiconductor device architecture requires line geometry to decrease below two microns, dimensional control using wet chemical techniques becomes more and more difficult. At one micron geometry, dry etching is essential and one of several etch techniques must be considered. **Figure 1** illustrates that the choices range from physical sputtering, with either conventional sputter etching or ion milling using energetic beam technology, to plasma chemical processes which create gaseous species from the etched material that can be pumped from the reaction chamber. Between these two limits lies reactive ion etching which uses the electrode excitation and operating pressure range of physical sputter etching together with the reactive gas species of plasma chemical etching. Although the etch machine utilized in these studies is configured to operate in any of these etching modes, the data presented here were generated in the RIE mode. Once the etch mode has been selected, the process is absolutely inseparable from the etch system. In the early history of plasma etching, it was not fully appreciated that the process must be intimately related to the etch machine through proper process control.

Basically, process control is achieved in one of two ways. The first is to optimize the chemistry so that high selectivity, etch profile control and acceptable etch rates are obtained. The second is to use an integrated approach in which a wafer or wafer array is monitored by an end point sensing system. The first method is microscopic in that atoms, free radicals, etc.,

are interacting with every part of the wafer. The second method is a macroscopic approach in which the totality of the substrates is integrated. Plasma spectroscopy and etch gas mass analysis are two such macroscopic techniques for process control. Because variations in film thickness, uniformity and density, prior processing history, plasma uniformity, gas flow patterns, etc., can affect macroscopic sensing, the ideal situation is to have favorable chemistry as the dominant working process control, and plasma or etch gas monitoring as secondary insurance.

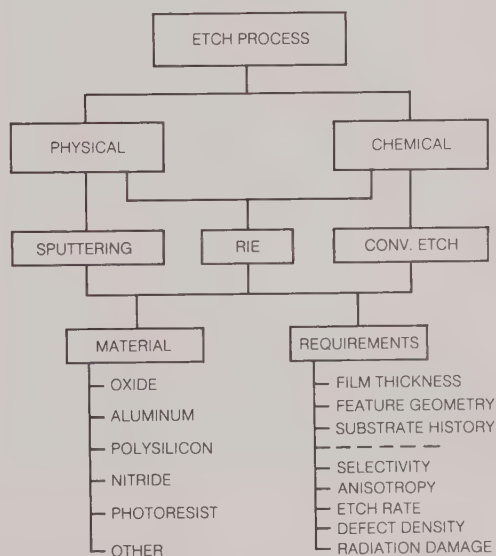


FIG. 1 Choices of Dry Etch Processes.

Experimental Method and Equipment

The system used in this study is the Perkin-Elmer Model 4440 production etching system shown in **Figure 2**. This system has been designed to permit etching in three different modes: reactive ion etching (RIE), conventional planar etching (CPE), and triode etching (TE). These three etching modes are diagrammed in **Figure 3**. In the reactive ion etching mode (**Figure 3a**), the substrates rest on the RF excited electrode (usually at 13.56 MHz). Self bias of the excited electrode is typically 500 to 700 V, depending primarily on the RF power and operating pressure. The usual pressure range for RIE is 10 to 40 mTorr. This system configuration has demonstrated straight or slightly tapered wall etch profiles.

The 4440 etching system is load locked to permit loading of wafers into the reaction chamber without exposing the reaction chamber to atmospheric contamination such as water vapor. Exposure to atmosphere can result in spalling of polymeric films that develop on the chamber surfaces. This in turn, results in particulate generation, and run-to-run nonreproducibility of the etch process. The reaction chamber is oil diffusion pumped through a baffle chilled to about -100°C by means of a refrigerator to reduce backstreaming from the diffusion pump. The -100°C temperature is sufficiently cold to perform the anti-backstreaming function without also resulting in a cryosorption surface for pumping of the halocarbon gases used in the etching processes. In addition, a Meissner surface with over 3100 cm^2 area is located within the reaction chamber and can be chilled to reduce the water vapor to provide mid- 10^{-7} Torr system base pressure, if desired.

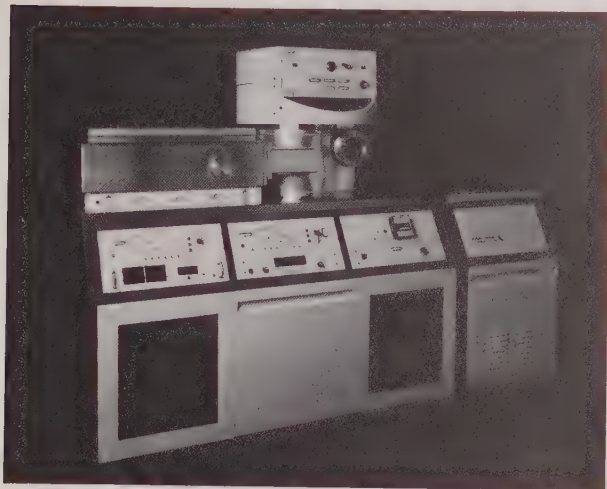


FIG. 2 The Perkin-Elmer Model 4440 production etching system with auxiliary mechanical pumping cabinet.

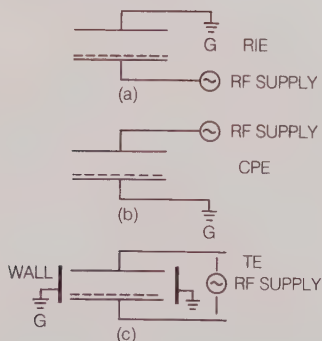


FIG. 3 Three modes of plasma etching are largely differentiated by the delivery of RF power to the electrodes.

The electrodes in the reactor are planar in configuration. The upper electrode is grounded in the RIE mode but can be RF excited. The lower electrode is a rotatable table which supports the substrate carrying pallet that is transported from the load lock. A gas inlet ring is coplanar and concentric with the upper electrode; gas flow is directed radially inward and toward the substrates. Gas flow for up to four gases can be electronically controlled via a servo valve system that permits individual gas control or total flow control with the partial flows ratio controlled to the primary gas. Simultaneous pressure control is achieved by varying the system pumping speed with a servo actuated throttle valve. Within a range near the pressure/flow regime of interest, this permits independent pressure and flow control.

To minimize variation of thermal effects within the reaction chamber, the chamber walls and upper electrode were water cooled and the rotating table was cooled to -5°C by means of a circulating ethylene glycol-water refrigeration system. At 1000W RF power, silicon wafer temperature was measured to be in the range $110\text{--}120^{\circ}\text{C}$. Control of wafer temperature is important for run-to-run reproducibility and to minimize photoresist degradation.

Experimental Results

Various mechanisms have been proposed for the plasma etching phenomena¹⁻⁷. Eprath² and Coburn³ have investigated the etching of SiO_2 in a mixture of CF_4 and H_2 . This mixture was, therefore, chosen to characterize the Model 4440 system so that comparisons with other studies could be drawn. The parameters of interest in the study were etch rates, selectivity, loading effects, uniformity, run-to-run reproducibility and etch profile. Each of these will be discussed to show their functional dependence on the various machine parameters; e.g., RF power, pressure, total gas flow, and flow mixture ratio of H_2 to CF_4 .

Etch Rate and Selectivity

These two parameters will be discussed together because selectivity is normally defined as the ratio of the etch rate of the film deposit to that of a subsurface film or substrate. The etch rate of SiO_2 is a function of RF power and gas pressure. There is only a very minor dependence on the CF_4 to H_2 ratio. **Figure 4** shows the RF power dependence of the etch rate of SiO_2 and polysilicon for one set of flow and pressure conditions. The oxide etch rate increases linearly with RF power but the silicon shows only slight rate increase with increasing power. The decrease in selectivity with increasing power is not fully understood but might indicate an increase in silicon etch rate at higher power due to physical sputter etching.

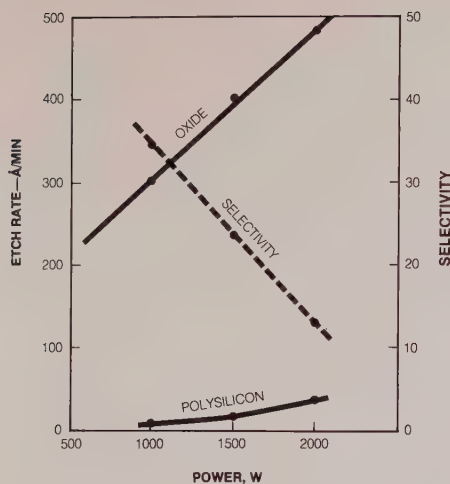


FIG. 4 Etch rates and selectivity of SiO_2 over polysilicon as a function of RF power with CF_4 to H_2 pressures in the ratio of 4 to 1, 20 mTorr total pressure, and 10 min. etch time.

Figure 5 gives the pressure dependence of the etch rates for constant flow. The dependence is not strong, which suggests that tight pressure control is not required. **Figure 6** shows that the SiO_2 etch rate is not a strong function of the H_2 to CF_4 flow rate ratio although the Si etch rate and, thus, the selectivity are strongly influenced by this ratio. At the point at which the etch rate becomes very small and the selectivity rises to high values, polymer is deposited on the substrate surface. If this occurs, a descumming operation, usually an oxygen plasma, is required to remove the deposit. For this reason, the H_2 flow is kept just under the level at which polymer forms and where

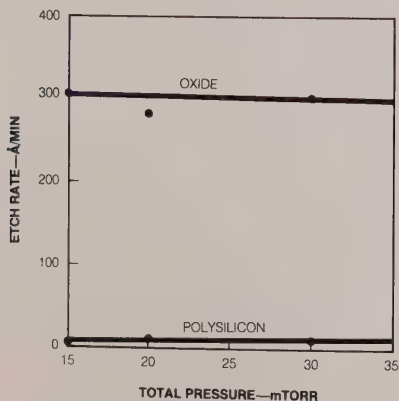


FIG. 5 Etch rates as a function of pressure for CF_4 to H_2 flow ratio of 1.1 and 1 kW RF power.

a reasonably high selectivity is obtained. The linear fit to the data predicts a zero etch rate for the polysilicon at a flow rate ratio near unity. This is confirmed in experiments which show polymer formation at flow ratios of 1.05, 1.2, and 1.3. The least squares linear fit also predicts a selectivity of 17 at a H_2/CF_4 flow ratio of 0.9, which is also observed.

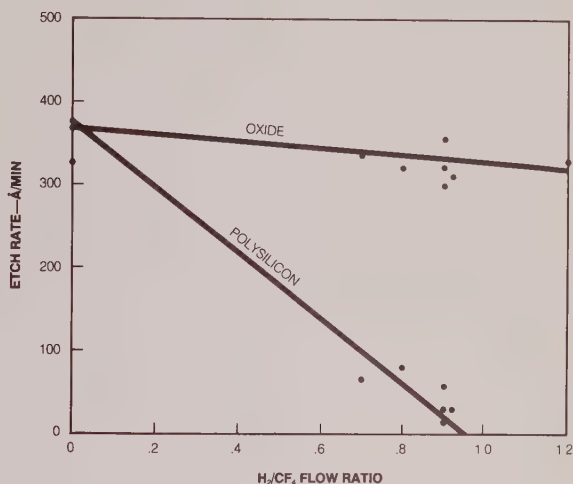


FIG. 6 Etch rates as a function of H_2 to CF_4 flow ratio at a pressure of 30 mTorr and 1 kW RF power.

Selectivity has been defined here as the ratio of the etch rates for SiO_2 and Si. The actual application of this definition can be problematical as shown in **Figure 7**. The observed etch rate for SiO_2 is independent of the etch time indicating that the etch depth proceeds linearly in time. The silicon substrate,

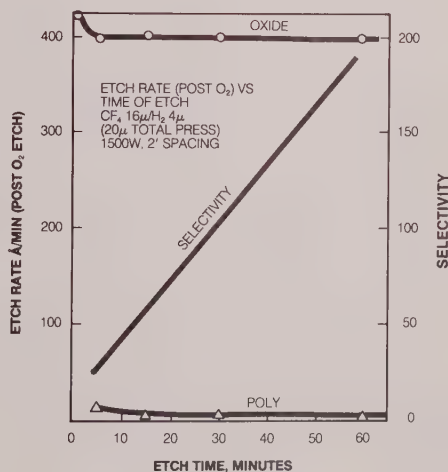


FIG. 7 Observed etch rates as a function of etch time demonstrating a problem with selectivity determination.

however, shows a decreasing average etch rate with increasing etch time. Coburn³ has shown that a carbon layer forms on the silicon surface which inhibits, but does not stop, further etching. The etch rate then is not constant but decreasing in time and the *apparent* selectivity can become very high. The problem becomes one of measurement because if the etch time is short to minimize this effect, the etch depth in silicon becomes very difficult to measure with accuracy. If a longer time is used to facilitate measurement, an inordinately high selectivity is calculated. In the measurements reported here, the etch time was standardized at 10 minutes which was a compromise between accurate etch rate measurement and inaccurate selectivity.

Loading Effects, Uniformity and Reproducibility

These parameters were evaluated together by doing consecutive etch runs with varying numbers of substrates and, at the same time, measuring etch depth uniformity on a run-to-run basis. **Figure 8** shows a typical series of five consecutive runs. The etch rate for SiO₂ remained constant with a deviation band of $\pm 5.3\%$. Approximately $\pm 2\%$ is attributable to the measurement technique which was a stylus-type surface profilometer. A linear least squares fit to the data results in a slope of 0.06 which confirms the constancy of the etch rate.

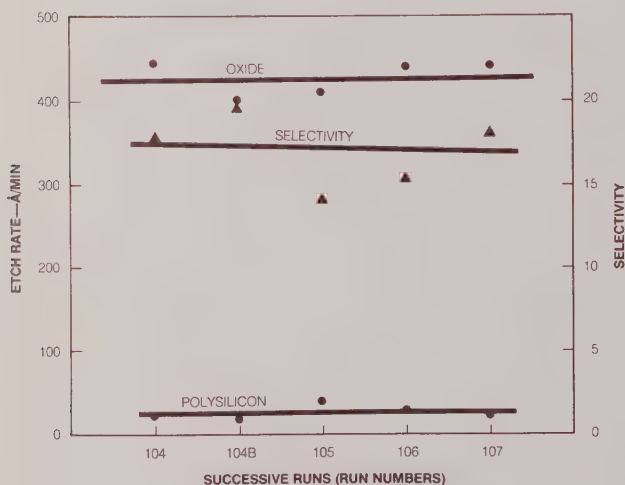


FIG. 8 Run-to-run reproducibility for a series of 5 runs at 1500W RF power.

Uniformity is taken to mean percent variation from greatest to the least etching measurement. Each wafer was measured at the center and at two points representing the radially innermost and outermost points relative to the pallet radius. The etch run load

varied from four wafers at a minimum to a full load of 30 wafers. The uniformity was then calculated from

$$\pm \% \text{ uniformity} = \frac{1}{2} \frac{\text{highest value} - \text{lowest value}}{\text{average}} \times 100.$$

Etch rates were found to be independent of load size, indicating that in the RIE mode used, no loading effects were observed. The uniformity within an etch cycle was typically better than $\pm 3.5\%$. The primary significance of this number is that the ideal control mechanism stated earlier, of optimum chemistry with plasma monitoring as back-up, is in fact, achievable. The dominant factors in achieving good uniformity are gas flow patterns and flow rates. Additionally, variations in plasma density resulting from the shape of the reaction chamber and perturbations or nonuniformity in the gas flow are averaged over all the substrates by rotation of the lower electrode. During the etch runs, samples were examined for contamination resulting from the pallet or other reactor surfaces. A Perkin-Elmer Model 590 Scanning Auger Microprobe was used to analyze the wafer surface and determine if contamination had resulted. A molybdenum pallet was used in the test but no evidence of molybdenum or constituents of stainless steel were detectable. The instrumental detection limit is .001 monolayers.

Etch Profile

Etch profile is not found to be a function of RF power, gas pressure, or gas flow within the range of parameters discussed here. **Figure 9** summarizes various etch profiles obtained in various plasma regimes. The vertical anisotropic profile is characteristic of the RIE etching mode and results from the plasma condition and surface potentials generated by the plasma adjacent to the substrates.⁸ Under the etching conditions described here, anisotropic to slightly directional anisotropic profiles are obtained as shown in **Figure 10**. These etch profiles were observed with a Perkin-Elmer ETEC Autoscan scanning electron microscope on samples of 1.2 micron thick SiO₂ etched at 30 mTorr gas pressure with CF₄ and H₂ flow rates of 33.0 and 29.8 sccm respectively and 1kW RF power. The wafers were patterned with negative photoresist which was stripped prior to SEM analysis.

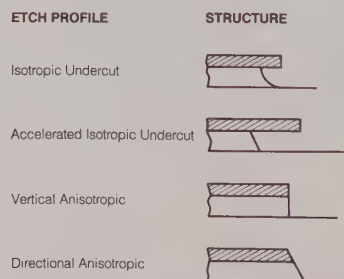


FIG. 9 Etch profile terminology and associated structures.

Prior to stripping, the resist showed no reticulation and appeared shiny.

During etching, typical photoresist erosion rates were measured to be 75-85 Å/min for AZ 1370 and 30-45 Å/min for KTI resists. Compared to SiO₂ this represents a selectivity of 5 to 10, which is satisfactory for most etch requirements.

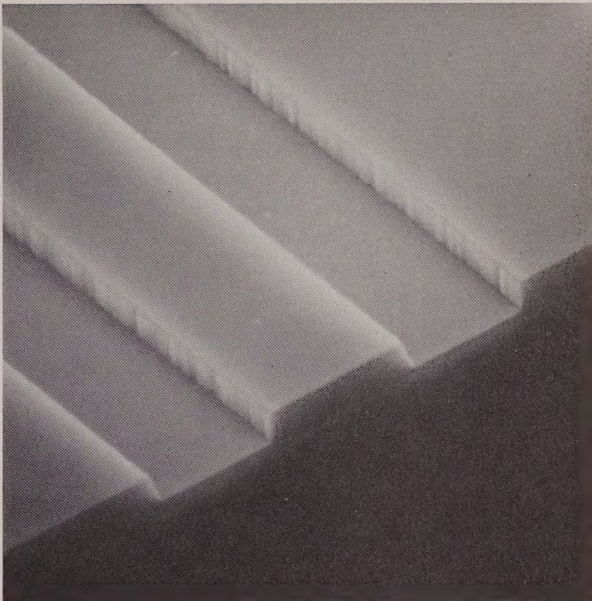
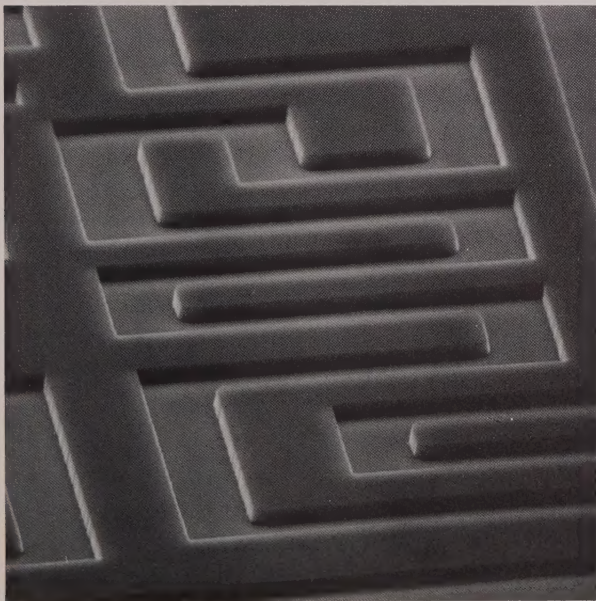
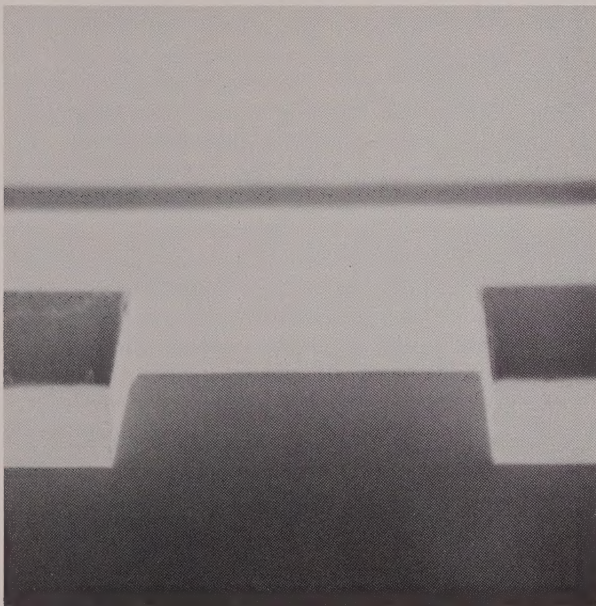


FIG. 10 SEM photographs of etch profile in 1.2 micron thick SiO₂.

Summary

Reactive ion etching of SiO₂ over polysilicon in the Perkin-Elmer Model 4440 production etching system has been shown to yield rate, selectivity, uniformity and profile results sufficient for many semiconductor fabrication requirements. The gas handling, wafer handling and pumping systems have been designed to provide wafer throughput commensurate with production rates. The data reported here indicate that successful RIE can be achieved in a large system producing results consistent with those observed in smaller, research reactor systems.

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